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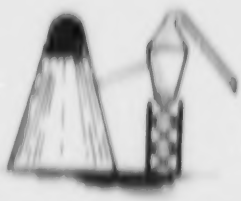

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16. Abstracts

Emission data obtained from source tests, material balance studies, engineering estimates, etc., have been compiled for use by individuals and groups responsible for conducting air pollution emission inventories. Emission factors given in this document, the result of the expansion and continuation of earlier work, cover most of the common emission categories: fuel combustion by stationary and mobile sources; combustion of solid wastes; evaporation of fuels, solvents, and other volatile substances; various industrial processes; and miscellaneous sources. When no specific source-test data are available, these factors can be used to estimate the quantities of primary pollutants (particulates, CO, SO_2, NO_x, and hydrocarbons) being released from a source or source group.

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7. METALLURGICAL INDUSTRY

The metallurgical industries can be broadly divided into primary and secondary metal production operations. The term primary metals refers to production of the metal from ore. The secondary metals industry includes the recovery of metal from scrap and salvage and the production of alloys from ingot.

The primary metals industries discussed in Sections 7.1 through 7.7 include the nonferrous operations of primary aluminum production, copper smelters, lead smelters, and zinc smelters. These industries are characterized by the large quantities of sulfur oxides and particulates emitted. The primary metals industry also includes iron and steel mills, ferroalloy production, and metallurgical coke manufacture.

The secondary metallurgical industries discussed in Sections 7.8 through 7.14 are aluminum operations, brass and bronze ingots, gray iron foundries, lead smelting, magnesium smelting, steel foundries, and zinc processing. The major air contaminants from these operations are particulates in the forms of metallic fumes, smoke, and dust.

7.1 PRIMARY ALUMINUM PRODUCTION

7.1.1 Process Description[1] *Revised by William M. Vatavuk*

Bauxite, a hydrated oxide of aluminum associated with silicon, titanium, and iron, is the base ore for aluminum production. Most bauxite ore is purified by the Bayer process in which the ore is dried, ground in ball mills, and mixed with sodium hydroxide. Iron oxide, silica, and other impurities are removed by settling, dilution, and filtration. The aluminum hydroxide is precipitated from this diluted, cooled solution and calcined to produce pure alumina, according to the reaction:

$$2Al(OH)_3 \longrightarrow 3H_2O + Al_2O_3 \qquad (1)$$

Aluminum hydroxide — Water — Alumina

Aluminum metal is manufactured by the Hall-Heroult process, which involves the electrolytic reduction of alumina dissolved in a molten salt bath of cryolite (a complex of $NaF \cdot AlF_3$) and various salt additives:

$$2Al_2O_3 \xrightarrow{\text{Electrolysis}} 4Al + 3O_2 \qquad (2)$$

Alumina — Aluminum + Oxygen

The electrolysis is performed in a carbon crucible housed in a steel shell, known as a "pot." The electrolysis employs the carbon crucible as the cathode (negative pole) and a carbon mass as the anode (positive pole). The type of anode configuration used distinguishes the three types of pots: prebaked (PB), horizontal-stud Soderberg (HSS), and vertical-stud Soderberg (VSS).

The major portion of aluminum produced in the United States (61.9 percent of 1970 production) is processed in prebaked cells. In this type of pot, the anode consists of blocks that are formed from a carbon paste and baked

in an oven prior to their use in the cell. These blocks, typically 14 to 24 per cell, are attached to metal rods and serve as replaceable anodes. As the reduction proceeds, the carbon in these blocks is gradually consumed (at a rate of about 1 inch per day) by reaction with the oxygen by-product (see Table 7.1-1).

Table 7.1-1. RAW MATERIAL AND ENERGY REQUIREMENTS FOR ALUMINUM PRODUCTION

Parameter	Representative value
Cell operating temperature	1742 F (950 C)
Current through pot line	60,000 to 125,000 amp
Voltage drop per cell	4.3 to 6.2
Current efficiency	85 to 90%
Energy required	6.0 to 8.5 kwh/lb aluminum (13.2 to 18.7 kwh/kg aluminum)
Weight alumina consumed	1.89 to 1.92 lb Al_2O_3/lb aluminum (1.89 to 1.92 kg Al_2O_3/kg aluminum)
Weight electrolyte fluoride consumed	0.03 to 0.10 lb fluoride/lb aluminum (0.03 to 0.10 kg fluoride/kg aluminum)
Weight carbon electrode consumed	0.45 to 0.55 lb electrode/lb aluminum (0.45 to 0.55 kg electrode/kg aluminum)

The second most commonly used furnace (25.8 percent of 1970 production) is the horizontal-stud Soderberg. This type of cell uses a "continuous" carbon anode; that is, a mixture of pitch and carbon aggregate called "paste" is added at the top of the superstructure periodically, and the entire anode assembly is moved downward as the carbon burns away. The cell anode is contained by aluminum sheeting and perforated steel channels, through which electrode connections, called studs, are inserted into the anode paste. As the baking anode is lowered, the lower row of studs and the bottom channel are removed, and the flexible electrical connections are moved to a higher row. One disadvantage of baking the paste in place is that heavy organic materials (tars) are added to the cell effluent stream. The heavy tars often cause plugging of the ducts, fans, and control equipment, an effect that seriously limits the choice of air cleaning equipment.

The vertical-stud Soderberg is similar to the horizontal-stud furnace, with the exception that the studs are mounted vertically in the cell. The studs must be raised and replaced periodically, but that is a relatively simple process. Representative raw material and energy requirements for aluminum reduction cells are presented in Table 7.1-1. A schematic representation of the reduction process is shown in Figure 7.1-1.

7.1.2 Emissions and Controls[1-3]

Emissions from aluminum reduction processes consist primarily of gaseous hydrogen fluoride and particulate fluorides, alumina, hydrocarbons or organics, sulfur dioxide from the reduction cells and the anode baking furnaces. Large amounts of particulates are also generated during the calcining of aluminum hydroxide, but the economic value of this dust is such that extensive controls have been employed to reduce emissions to relatively small quantities. Finally, small amounts of particulates are emitted from the bauxite grinding and materials handling processes.

The source of fluoride emissions from reduction cells is the fluoride electrolyte, which contains cryolite, aluminum fluoride (AlF_3), and fluorspar (CaF_2). For normal operation, the weight ratio of "bath" (ratio of sodium fluoride (NaF) to AlF_3) is maintained between 1.35 and 1.43 by the addition of Na_3AlF_6, NaF, and AlF_3. Experience has shown that increasing this ratio has the effect of decreasing total fluoride effluents. Cell fluoride emissions are also decreased by lowering the operating temperature and increasing the alumina content in the bath. Specifically, the ratio of gaseous (mainly hydrogen fluoride) to particulate fluorides varies from 1.2 to 1.7 with PB and HSS cells, but attains a value of approximately 3.0 with VSS cells.

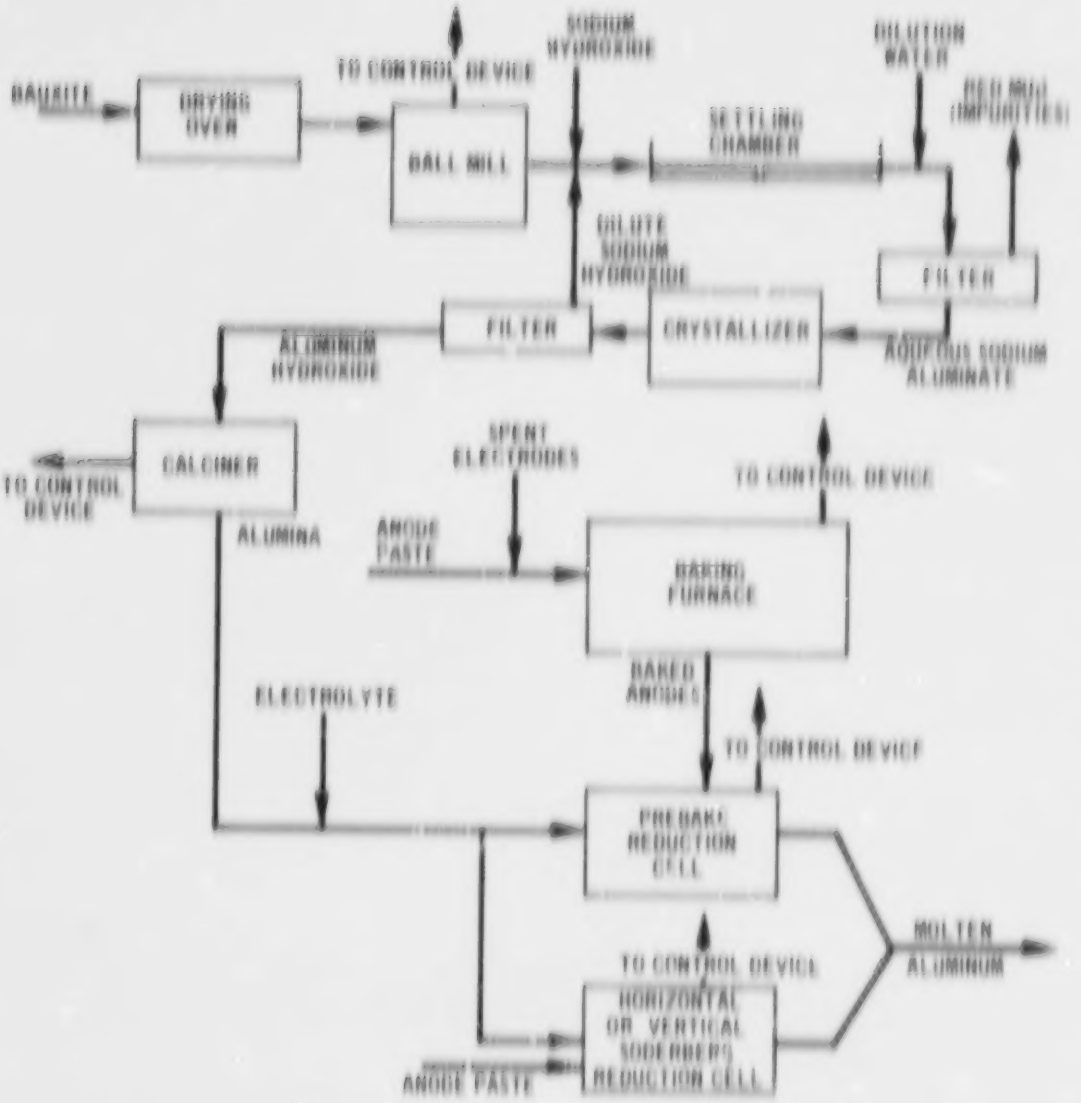

Figure 7.1-1. Schematic diagram of primary aluminum production process.

Table 7.1.2. REPRESENTATIVE PARTICLE SIZE DISTRIBUTIONS OF UNCONTROLLED EFFLUENTS FROM PREBAKED AND HORIZONTAL STUD SODERBERG CELLS[1]

Size range, μm	Particles within size range, wt %	
	Prebaked	Horizontal stud Soderberg
<1	35	44
1 to 5	25	26
5 to 10	8	8
10 to 20	5	6
20 to 44	5	4
>44	22	12

Particulate emissions from reduction cells consist of alumina and carbon from anode dusting, cryolite, aluminum fluoride, calcium fluoride, chiolite ($Na_5Al_3F_{14}$), and ferric oxide. Representative size distributions for PB and HSS particulate effluents are presented in Table 7.1.2. Particulates less than 1 micron in diameter represent the largest percentage (35 to 44 percent by weight) of uncontrolled effluents.

Moderate amounts of hydrocarbons derived from the anode paste are emitted from horizontal- and vertical-Soderberg pots. In vertical cells these compounds are removed by combustion via integral gas burners before the off gases are released.

Because many different kinds of gases and particulates are emitted from reduction cells, many kinds of control devices have been employed. To abate both gaseous and particulate emissions, one or more types of wet scrubbers – spray tower and chambers, quench towers, throating beds, packed beds, venturis, and self-induced sprays – are used on all three cells and on anode baking furnaces. In addition, particulate control methods, such as electrostatic precipitators (wet and dry), multiple cyclones, and dry scrubbers (fluid-bed and coated-filter types), are employed with baking furnaces on PB and VSS cells. Dry alumina adsorption has been used at several PB and VSS installations in foreign countries. In this technique, both gaseous and particulate fluorides are controlled by passing the pot off-gases through the entering alumina feed, on which the fluorides are absorbed; the technique has an overall control efficiency of 98 percent.

In the aluminum hydroxide calcining, bauxite grinding, and materials handling operations, various dry dust collection devices such as centrifugal collectors, multiple cyclones, or electrostatic precipitators and wet scrubbers or both may be used. Controlled and uncontrolled emission factors for fluorides and total particulates are presented in Table 7.1.3.

Table 7.1-3. EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[1]
EMISSION FACTOR RATING: A

Type of operation	Total particulate[2]		Gaseous fluorides (HF)		Particulate fluorides (F)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Bauxite grinding[3,4]						
Uncontrolled	6.0	3.0	Neg	Neg	NA[5]	NA
Spray tower	1.8[6]	0.90	Neg	Neg	NA	NA
Floating-bed scrubber	1.7	0.85	Neg	Neg	NA	NA
Quench tower and spray screen	1.0	0.50	Neg	Neg	NA	NA
Electrostatic precipitator	2.12	0.060	Neg	Neg	NA	NA
Calcining of aluminum hydroxide[3,7]						
Uncontrolled	200.0	100.0	Neg	Neg	NA	NA
Spray tower	60.0	30.0	Neg	Neg	NA	NA
Floating-bed scrubber	56.0	28.0	Neg	Neg	NA	NA
Quench tower and spray screen	34.0	17.0	Neg	Neg	NA	NA
Electrostatic precipitator	4.0	2.0	Neg	Neg	NA	NA
Anode baking furnace[3]						
Uncontrolled	3.0 (1.0 to 5.0)[8]	1.5 (0.5 to 2.5)	0.93	0.47	Neg	Neg
Spray tower	NA	NA	0.0372	0.0186	Neg	Neg
Dry electrostatic precipitator	1.13	0.57	0.93	0.47	Neg	Neg
Self-induced spray	0.06	0.03	0.0372	0.0186	Neg	Neg
Potalaid reduction cell[9]						
Uncontrolled	81.3 (11.9 to 177.0)	40.65 (5.95 to 88.5)	24.7 (13.8 to 34.6)	12.35 (3.9 to 17.4)	20[4] (4.8 to 35.5)	10.7 (4.9 to 17.8)
Multiple cyclone	17.9	8.95	24.7	12.35	4.48	2.25
Fluid-bed dry scrubber system	2.82	1.31	0.247	0.124	0.537	0.253

Table 7.1-3 (continued). EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[a]

EMISSION FACTOR RATING: A

Type of operation	Total particulate[b]		Gaseous fluorides (HF)		Particulate fluorides (F)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
scrubber system						
Cooled filter/ dry scrubber	1.62	0.81	1.98 to 5.93	0.99 to 2.97	0.408	0.204
Dry electrostatic precipitator	1.62 to 8.94	0.81 to 4.47	29.7	12.35	0.408 to 2.24	0.204 to 1.12
Spray tower	16.2	8.1	0.4694 to 2.72	0.247 to 1.36	4.08	2.04
Floating bed scrubber	16.2	8.1	0.4694	0.247	4.08	2.04
Chamber scrubber	12.2	6.1	2.96	1.48	3.06	1.53
Vertical flow packed bed	12.2	6.1	8.4	4.2	3.06	1.53
Dry alumina adsorption	1.62	0.81	0.494	0.247	0.408	0.204
Horizontal-stud Soderberg cell[c]						
Uncontrolled	98.4 (60.6 to 194.0)	49.2 (46.8 to 52.0)	26.6 (25.2 to 28.8)	13.3 (12.6 to 14.4)	15.0 (14.4 to 16.2)	7.5 (7.2 to 8.1)
Spray tower	19.6 to 36.4	9.8 to 18.2	1.96 to 2.39	0.93 to 1.195	2.12 to 5.77	1.56 to 2.885
Floating bed scrubber	21.6	10.8	0.522	0.366	0.340	0.1715
Wet electrostatic precipitator	7.10	3.55	26.6	13.3	1.13	0.562
Vertical-stud Soderberg cell						
Uncontrolled	78.4	39.2	30.4 (28.0 to 35.0)	15.2 (10.0 to 17.5)	10.6 (5.6 to 80.3)	5.3 (2.8 to 37.7)
Spray tower	19.6	9.8	0.3674	0.1521	2.65	1.325
Self-reduced spray	NA	NA	0.3354	0.1521	NA	NA
Venturi scrubber	3.14	1.57	0.3354	0.1521	0.424	0.212
Wet electrostatic precipitator	0.784 to 7.84	0.392 to 2.52	30.4	15.2	0.106 to 1.06	0.053 to 0.53
Multiple cyclones	3.92 to 4.7	1.96 to 2.35	30.4	15.2	5.30 to 6.36	2.65 to 3.18
Dry alumina adsorption	1.57	0.784	0.608	0.3354	0.212	0.106
Materials handling[d]						
Uncontrolled	10.0	5.0	Negl.	Negl.	NA	NA
Spray tower	3.0	1.5	Negl.	Negl.	NA	NA

Table 7.1.3 (continued). EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[1]

EMISSION FACTOR RATING: A

Type of operation	Total particulate[2]		Gaseous fluorides (HF),		Particulate fluorides (F),	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Floating-bed scrubber	2.8	1.4	Neg	Neg	NA	NA
Quench tower and spray screen	1.7	0.85	Neg	Neg	NA	NA
Electrostatic precipitator	0.20	0.10	Neg	Neg	NA	NA

[1]Emission factors for bauxite grinding expressed as pounds per ton (kg/MT) of bauxite processed. Factors for calcining of aluminum hydroxide expressed as pounds per ton (kg/MT) of aluminum produced. All other factors in terms of tons (MT) of molten aluminum produced.

[2]Includes particulate fluorides.

[3]References 1 and 2.

[4]No information available.

[5]Controlled emission factors are based on average uncontrolled factors and on average observed collection efficiencies.

[6]References 1,2, and 4 through 6.

[7]Numbers in parentheses are ranges of uncontrolled values observed.

[8]References 2 and 4 through 6.

[9]Reference 1.

[10]References 2 and 6.

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7.3 METALLURGICAL COKE MANUFACTURING

7.3.1 Process Description[1]

Coking is the process of heating coal in an atmosphere of low oxygen content, i.e., destructive distillation. During this process, organic compounds in the coal break down to yield gases and a residue of relatively nonvolatile nature. Two processes are used in the manufacture of metallurgical coke: the beehive process and the by-product process; the by-product process accounts for more than 98 percent of the coke produced.

Beehive oven.[1] The beehive is a refractory-lined enclosure with a dome-shaped roof. The coal charge is deposited onto the floor of the beehive and leveled to give a uniform depth of material. Openings in the beehive oven are then restricted to control the amount of air reaching the coal. The carbonization process begins at the coal at the top of the pile and works down through it. The volatile matter being distilled escapes to the atmosphere through a hole in the roof. At the completion of the coking time, the coke is "watered out" or quenched.

By-product process.[1] The by-product process is oriented toward the recovery of the gases produced during the coking cycle. The rectangular coking ovens are grouped together in a series, alternately interspersed with heating flues, called a coke battery. Coal is charged to the ovens through ports in the top, which are then sealed. Heat is supplied to the ovens by burning some of the coke gas produced. Coking is largely accomplished at temperatures of 2000°F to 2100°F (1100°C to 1150°C) for a period of about 16 to 20 hours. At the end of the coking period, the coke is pushed from the oven by a ram and quenched with water.

7.3.2 Emissions[1]

Visible smoke, hydrocarbons, carbon monoxide, and other emissions originate from the following by-product coking operations: (1) charging of the coal into the incandescent ovens, (2) oven leakage during the coking period, (3) pushing the coke out of the ovens, and (4) quenching the hot coke. Virtually no attempts have been made to prevent gaseous emissions from beehive ovens. Gaseous emissions from the by-product ovens are drawn off to a collecting main and are subjected to various operations for separating ammonia, coke-oven gas, tar, phenol, light oil (benzene, toluene, xylenes), and pyridine. These unit operations are potential sources of hydrocarbon emissions.

Oven-charging operations and leakage around poorly sealed coke-oven doors and lids are major sources of gaseous emissions from by-product ovens. Sulfur is present in coke-oven gas in the form of hydrogen sulfide and carbon disulfide. If the gas is not desulfurized, the combustion process will emit sulfur dioxide.

Associated with both coking processes are the material-handling operations of unloading coal, storing coal, grinding and sizing of coal, screening and crushing coke, and storing and loading coke. All of these operations are potential particulate emission sources. In addition, the operations of oven charging, coke pushing and quenching produce particulate emissions. The emission factors for coking operations are summarized in Table 7.3-1.

Table 7.21. EMISSION FACTORS FOR METALLURGICAL COKE MANUFACTURE WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of operation	Particulate		Sulfur dioxide		Carbon monoxide		Hydrocarbons[b]		Nitrogen oxides (NO_x)		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
By-product coking[c]												
Unloading	0.4	0.2										
Charging	7.5	3.75	0.02	0.01	0.4	0.2	2.5	1.25	0.03	0.015	0.02	0.01
Coking cycle	0.7	0.35			0.4	0.2	1.5	0.75	0.07	0.035	0.04	0.02
Discharging	0.6	0.3			0.07	0.035	0.2	0.1			0.1	0.05
Quenching	0.9	0.45										
Underfiring[d]			4	2								
Bottom (ash)[e]	200	100			1	0.5	4	2			2	1

[a] Emission factors expressed as units per ton (weight) of coal charged.

[b] Expressed as methane.

[c] References 2 and 3.

[d] References 3, 5. The sulfur dioxide factor is based on the following representative conditions: (1) sulfur content of coal charged to oven is 0.8 percent by weight, (2) about 20 percent by weight of total sulfur in the coal charged to oven is transformed to the clean-burn gas, (3) about 40 percent of clean-burn gas is burned by the underfiring operation and the remainder is used in other parts of the plant operations where the rest of the sulfur dioxide is discharged, about 0.4 lb from 2 kg/MT of coal charged, and (4) gas which is underfiring has not been desulfurized.

[e] References 1 and 4.

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7.1 COPPER SMELTING

7.1.1 Process Description[1-2]

Copper is produced primarily from low-grade sulfide ores, which are concentrated by gravity and flotation methods. Copper is recovered from the concentrate by four steps: roasting, smelting, converting, and refining. Copper sulfide concentrates are normally roasted in either multiple-hearth or fluidized-bed roasters to remove the sulfur and then calcined in preparation for smelting in a reverberatory furnace. For about half the smelters the roasting step is eliminated. Smelting removes other impurities as a slag with the aid of fluxes. The matter that results from smelting is blown with air to remove the sulfur as sulfur dioxide, and the end product is a crude metallic copper. A refining process further purifies the metal by treatment of green logs or natural gas. This is often followed by electrolytic refining.

7.1.2 Emissions and Controls[2]

The high temperatures attained in roasting, smelting, and converting cause volatilization of a number of the trace elements present in copper ores and concentrates. The raw waste gases from these processes contain not only these fumes but also dust and sulfur oxide. Carbon monoxide and nitrogen oxides may also be emitted, but no quantitative data have been reported in the literature.

The value of the volatilized elements dictates efficient collection of fumes and dusts. A combination of cyclones and electrostatic precipitators seems to be most often used. Table 7.1-1 summarizes the uncontrolled emissions of particulates and sulfur oxides from copper smelters.

Table 7.3-1. EMISSION FACTORS FOR PRIMARY COPPER SMELTERS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of operation	Particulates[b, c]		Sulfur oxides[d]	
	lb/ton	kg/MT	lb/ton	kg/MT
Roasting	45	22.5	60	30
Smelting (reverberatory furnace)	20	10	320	160
Converting	60	30	870	435
Refining	10	5	-	-
Total uncontrolled	135	67.5	1250	625

[a]Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal. Emission factors expressed as units per unit weight of concentrated ore produced.
[b]References 2 through 4.
[c]Electrostatic precipitators have been reported to reduce emissions by 99.7 percent.
[d]Sulfur oxides can be reduced by about 90 percent by using a combination of sulfuric acid plants and lime slurry scrubbing.

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7.4 FERROALLOY PRODUCTION

7.4.1 Process Description[1-3]

Ferroalloy is the generic term for alloys consisting of iron and one or more other metals. Ferroalloys are used in steel production as alloying elements and deoxidants. There are three basic types of ferroalloys: (1) silicon-based alloys, including ferrosilicon and calciumsilicon; (2) manganese-based alloys, including ferromanganese and silicomanganese; and (3) chromium-based alloys, including ferrochromium and ferrosilicochrome.

The four major procedures used to produce ferroalloy and high-purity metallic additives for steelmaking are: (1) blast furnace, (2) electrolytic deposition, (3) aluminum silicothermic process, and (4) electric smelting furnace. Because over 75 percent of the ferroalloys are produced in electric smelting furnaces, this section deals only with that type of furnace.

The oldest, simplest, and most widely used electric furnaces are the submerged-arc open type, although semi-covered furnaces are also used. The alloys are made in the electric furnaces by reduction of suitable oxides. For example, in making ferrochromium the charge may consist of chrome ore, limestone, quartz (silica), coal and wood chips, along with scrap iron.

7.4.3 Emissions[3]

The production of ferroalloys has many dust- or fume-producing steps. The dust resulting from raw material handling, mix delivery, and crushing and sizing of the solidified product can be handled by conventional techniques and is ordinarily not a pollution problem. By far the major pollution problem arises from the ferroalloy furnaces themselves. The conventional submerged-arc furnace utilizes carbon reduction of metallic oxides and continuously produces large quantities of carbon monoxide. This escaping gas carries large quantities of particulates of submicron size, making control difficult.

In an open furnace, essentially all of the carbon monoxide burns with induced air at the top of the charge, and CO emissions are small. Particulate emissions from the open furnace, however, can be quite large. In the semi-closed furnace, most or all of the CO is withdrawn from the furnace and burns with dilution air introduced into the system. The unburned CO goes through particulate control devices and can be used as boiler fuel or can be flared directly. Particulate emission factors for electric smelting furnaces are presented in Table 7.4-1. No carbon monoxide emission data have been reported in the literature.

Table 7.4-1. EMISSION FACTORS FOR FERROALLOY PRODUCTION IN ELECTRIC SMELTING FURNACES[a]
EMISSION FACTOR RATING: C

Type of furnace and product	Particulates	
	lb/ton	kg/MT
Open furnace		
90% FeSi[b]	200	100
75% FeSi[c]	315	157.5
65% FeSi[b]	565	282.5
Silicon metal[d]	625	312.5
Silicomanganese[e]	195	97.5
Semi-covered furnace		
Ferromanganese[f]	45	22.5

[a]Emission factors expressed as units per unit weight of specified product produced.
[b]Reference 4.
[c]References 6 and 8.
[d]References 4 and 7.
[e]Reference 6.

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7.5 IRON AND STEEL MILLS

Revised by William M. Vatavuk and I. K. Felleisen

7.5.1 General[1]

Iron and steel manufacturing processes may be grouped into five distinct sequential operations: (1) coke production; (2) pig iron manufacture in blast furnaces; (3) steel making processes using basic oxygen, electric arc, and open hearth furnaces; (4) rolling mill operations; and (5) finishing operations (see Figure 7.5-1). The first three of these operations encompass nearly all of the air pollution sources. Coke production is discussed in detail elsewhere in this publication.

7.5.1.1 Pig Iron Manufacture[2,3] Pig iron is produced in blast furnaces, which are large refractory-lined chambers into which iron ore, coke, and limestone are charged and allowed to react with large amounts of hot air to produce molten iron. Slag and blast furnace gases are by-products of this operation. The production of 1 unit weight of pig iron requires an average charge of 1.88 unit weights of iron-bearing charge, 0.55 unit weight of coke, 0.20 unit weight of limestone, and 2.3 unit weight of air. Blast furnace by-products consist of 0.2 unit weight of slag, 0.03 unit weight of flue dust, and 3.5 unit weights of gas per unit of pig iron produced. Most of the coke used in the process is produced in by-product coke ovens. The flue dust and excess iron ore fines from the process are converted into useful blast furnace charge via sintering operations.

Blast furnace combustion gas and the gases that escape from bleeder openings constitute the major sources of particulate emissions. The dust in the gas consists of 35 to 50 percent iron, 4 to 14 percent carbon, 8 to 13 percent silicon dioxide, and small amounts of aluminum oxide, manganese oxide, calcium oxide, and other materials. Because of its high carbon monoxide content, this gas has a low heating value (about 1080 Btu/ft3) and is utilized as a fuel within the steel plant. Before it can be efficiently oxidized, however, the gas must be cleaned of particulates. Initially, the gases pass through a settling chamber or dry cyclone, where about 60 percent of the dust is removed. Next, the gases undergo a one- or two-stage cleaning operation. The primary cleaner is normally a wet scrubber, which removes about 90 percent of the remaining particulates. The secondary cleaner is a high-energy wet scrubber (usually a venturi) or an electrostatic precipitator, either of which can remove up to 90 percent of the particulates that have passed through the primary cleaner. Taken together, these control devices provide an overall dust removal efficiency of approximately 96 percent.

All of the carbon monoxide generated in the gas is normally used for fuel. Conditions such as "slips," however, can cause instantaneous emissions of carbon monoxide. Improvements in techniques for handling blast furnace burden have greatly reduced the occurrence of slips. In Table 7.5-1 particulate and carbon monoxide emission factors are presented for blast furnaces.

7.5.1.2 Steel-Making Processes

7.5.1.2.1 Open Hearth Furnaces[2,3] In the open hearth process, a mixture of scrap iron, steel, and pig iron is melted in a shallow rectangular basin, or "hearth," to which various liquid gaseous fuels provide the heat. Impurities are removed in a slag.

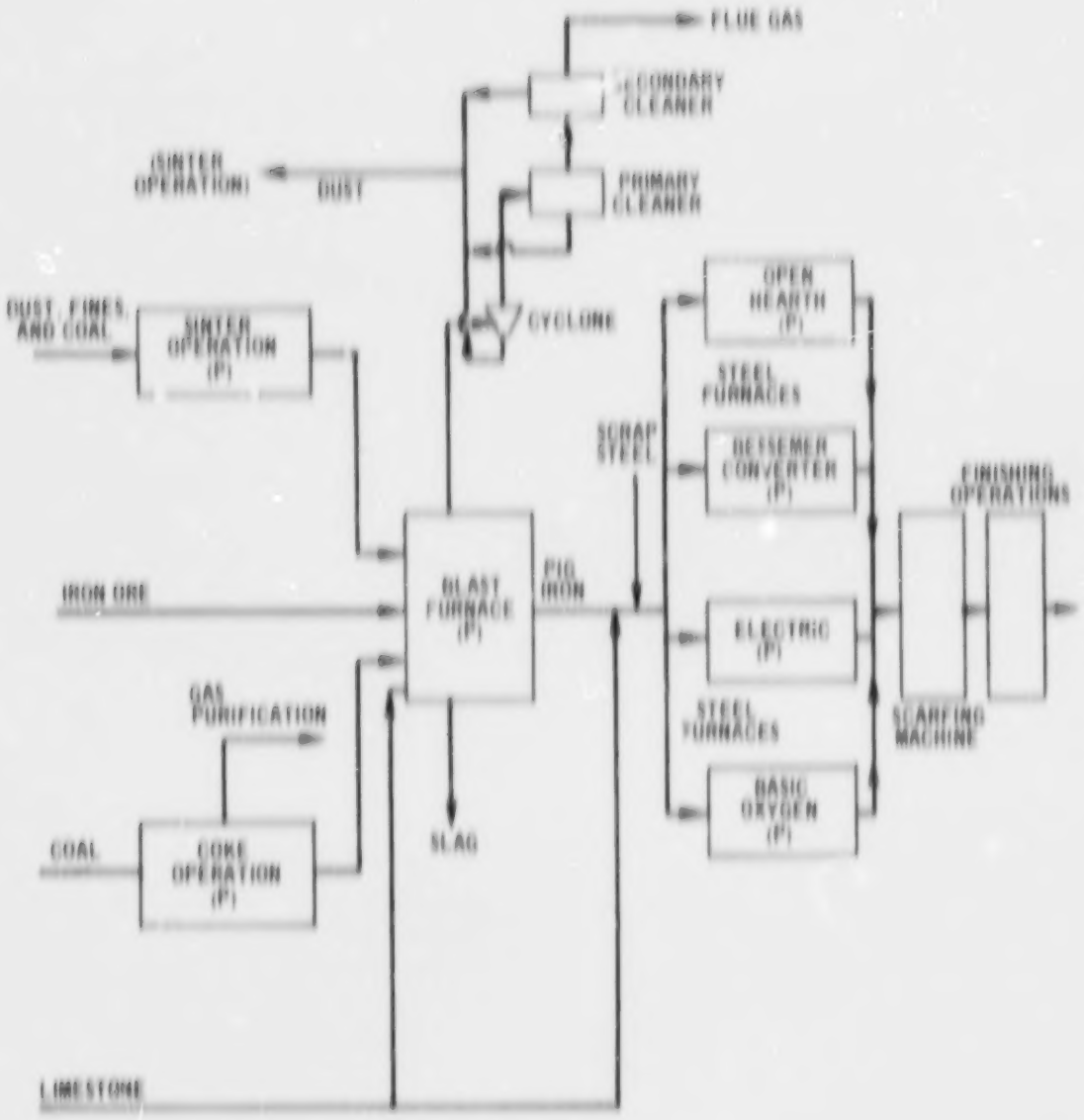

Figure 7.5-1. Basic flow diagram of iron and steel processes. "P" denotes a major source of particulate emissions.

Emissions from open hearths consist of particulates and small amounts of fluorides when fluoride-bearing ore, fluorspar, is used in the charge. The particulates are composed primarily of iron oxides, with a large portion (45 to 50 percent) in the 0 to 5 micrometer size range. The quantity of dust in the off gas increases considerably when oxygen lancing is used (see Table 7.5-1).

The devices most commonly used to control the iron oxide and fluoride particulates are electrostatic precipitators and high-energy venturi scrubbers, both of which effectively remove about 98 percent of the particulates. The scrubbers also remove nearly 99 percent of the gaseous fluorides and 95 percent of the particulate fluorides.

7.5.1.2.2 Basic Oxygen Furnaces[2-3] The basic oxygen process, also called the Linz-Donawitz (LD) process, is employed to produce steel from a furnace charge composed of approximately 70 percent molten blast-furnace metal and 30 percent scrap metal by use of a stream of commercially pure oxygen to oxidize the impurities, principally carbon and silicon.

The reaction that converts the molten iron into steel generates a considerable amount of particulate matter, largely in the form of iron oxide, although small amounts of fluorides may be present. Probably as the result of the tremendous agitation of the molten bath by the oxygen lancing, the dust loadings vary from 5 to 8 grains per standard cubic foot (11 to 18 grams/standard cubic meter) and high percentages of the particles are in the 0 to 5 micrometer size range.

In addition, tremendous amounts of carbon monoxide (140 lb/ton of steel and more) are generated by the reaction. Combustion in the hood, direct flaring, or some other means of ignition is used in the stack to reduce the actual carbon monoxide emissions to less than 3 lb/ton (1.5 kg/MT).

The particulate control devices used are venturi scrubbers and electrostatic precipitators, both of which have overall efficiencies of 99 percent. Furthermore, the scrubbers are 99 percent efficient in removing gaseous fluorides (see Table 7.5-1).

7.5.1.2.3 Electric Arc Furnaces[2-3] Electric furnaces are used primarily to produce special alloy steels or to melt large amounts of scrap for reuse. Heat is furnished by direct-arc electrodes extending through the roof of the furnace. In recent years, oxygen has been used to increase the rate of uniformity of scrap-melt-down and to decrease power consumption.

The particulates, primarily oxides of iron, manganese, aluminum, and silicon, that evolve when steel is being processed in an electric furnace result from the exposure of molten steel to extremely high temperatures. The quantity of these emissions is a function of the cleanliness and composition of the scrap metal charge, the refining procedure used (with or without oxygen lancing), and the refining time. As with open hearths, many of the particulates (40 to 75 percent) are in the 0 to 5 micrometer range. Additionally, moderate amounts of carbon monoxide (15 to 20 lb/ton) are emitted.

Particulate control devices most widely used with electric furnaces are venturi scrubbers, which have a collection efficiency of approximately 98 percent, and bag filters, which have collection efficiencies of 99 percent or higher.

7.5.1.3 Scarfing[1] Scarfing is a method of surface preparation of semi-finished steel. A scarfing machine removes surface defects from the steel billets and slabs, before they are shaped or rolled, by applying jets of oxygen to the surface of the steel, which is at orange heat, thus removing a thin upper layer of the metal by rapid oxidation.

Emissions from scarfing operations consist of iron oxide fumes. The rate at which particulates are emitted is dependent on the condition of the billets or slabs and the amount of metal removal required (Table 7.5-1). Emission control techniques for the removal of fine particles vary among steel producers, but one of the most commonly used devices is the electrostatic precipitator, which is approximately 94 percent efficient.

Table 7.5-1. EMISSION FACTORS FOR IRON AND STEEL MILLS[a,b]
EMISSION FACTOR RATINGS: A (PARTICULATES AND CARBON MONOXIDE)
C (FLUORIDES)

Type of operation	Total particulates		Carbon monoxide		Fluorides[c,d]			
					Gaseous (HF)		Particulates (CaF_2)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Pig iron production								
Blast furnace[e]								
Dry charge, uncontrolled	110	55	1750 (1400 to 2100)	875 (700 to 1050)[f]	–	–	–	–
Agglomerate charge, uncontrolled	40	20	–	–	–	–	–	–
Total, uncontrolled	150 (130 to 200)	75 (65 to 100)	1750 (1400 to 2100)	875 (700 to 1050)	–	–	–	–
Settling chamber or dry cyclone	60	30	–	–	–	–	–	–
Plus wet scrubber	15	7.5	–	–	–	–	–	–
Plus venturi or electrostatic precipitator	1.5	0.75	–	–	–	–	–	–
Sintering[g]								
Windbox, uncontrolled[h]	20	10	–	–	–	–	–	–
Dry cyclone	2.0	1.0	–	–	–	–	–	–
Dry cyclone plus elec. mostatic precipitator	1.0	0.5	–	–	–	–	–	–
Dry cyclone plus wet scrubber	0.04	0.02	–	–	–	–	–	–
Discharge, uncontrolled	22	11	44	22	–	–	–	–
Dry cyclone	2.2	1.1	44	22	–	–	–	–
Dry cyclone plus elec. mostatic precipitator	0.11	0.055	44	22	–	–	–	–
Steel production								
Open hearth[i]								
No oxygen lance, uncontrolled	8.0 (5.0 to 12.0)	4.15 (2.9 to 6.0)	–	–	0.100	0.05	0.030	0.015
Venturi scrubber	0.17	0.085	–	–	0.011	0.0055	0.0015	0.0008
Electrostatic precipitator	0.17	0.085	–	–	0.100	0.050	0.0136	0.0068
Oxygen lance, uncontrolled	17.4 (8.2 to 22.0)	8.7 (4.65 to 11.0)	–	–	0.100	0.050	0.030	0.015

Table 7.5-1 (continued). EMISSION FACTORS FOR IRON AND STEEL MILLS[a-b]
EMISSION FACTOR RATINGS: A (PARTICULATES AND CARBON MONOXIDE); C (FLUORIDES)

Type of operation	Total particulate		Carbon monoxide		Fluorides[c,d]			
					Gaseous (HF)		Particulate (CaF_2)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Venturi scrubber	0.17	0.085	--	--	0.0111	0.00555	0.00115	0.00058
Electrostatic precipitator	0.35	0.175	--	--	0.1126	0.0563	0.00006	0.00003
Basic oxygen, uncontrolled[e]	51 (32 to 86)	25.5 (16 to 43)	139 (104 to 227)	69.5 (52.0 to 116.5)	Neg	Neg	0.2000	0.1000
Venturi scrubber	0.57	0.285	--	--	--	--	0.0002	0.0001
Electrostatic precipitator	0.51	0.255	--	--	--	--	0.0002	0.0001
Spray chamber	15.3	7.65	--	--	--	--	0.0060	0.0030
Electric arc[f]								
No oxygen lance[g], uncontrolled	9.2 (7.0 to 10.6)	4.6 (3.5 to 5.3)	18	9	0.0112	0.0056	0.2228	0.1114
Venturi scrubber	0.18	0.09	18	9	0.00018	0.00009	0.0111	0.00555
Electrostatic precipitator	0.28 to 0.74	0.14 to 0.37	18	9	0.0112	0.0056	0.0111	0.00555
Bagfilter	0.09	0.045	18	9	0.0112	0.0056	0.00224	0.00112
Oxygen lance,[h] uncontrolled	11	5.5	18	9	0.0112	0.0056	0.2228	0.1114
Venturi scrubber	0.22	0.11	18	9	0.00112	0.00056	0.0111	0.00555
Electrostatic precipitator	0.33 to 0.88	0.165 to 0.44	18	9	0.0112	0.0056	0.0111	0.00555
Bagfilter	0.11	0.055	18	9	0.0112	0.0056	0.00224	0.00112
Scarfing[i], uncontrolled	<1	<0.5	--	--	--	--	--	--
Electrostatic precipitator	<0.06	<0.03	--	--	--	--	--	--
Venturi scrubber	<0.02	<0.01	--	--	--	--	--	--

[a] Emission factors expressed as units per ton or weight of metal produced.
[b] Numbers in parentheses after uncontrolled values are ranges. Controlled factors are calculated using average uncontrolled factors and observed equipment efficiencies.
[c] Reference 4.
[d] Value included in "Total Particulate" figure.
[e] References 2, 3, and 5.
[f] These factors should be used to estimate particulate and carbon monoxide emissions from the entire steel furnace operations. The total particulate factors for non-oxygen and eight-minute oxygen apply only to these operations.
[g] References 3.
[h] Approximately 0.2 pounds of sulfur dioxide per ton (0.10 kg/MT) of carbon is produced at scrubber.
[i] References, 2, 3, 5, and 6.
[j] References 2 through 10.
[k] Values are for carbon type electric arc furnaces. For alloy type furnaces, multiply given values by 2.86.
[l] References 2 through 5.
[m] References 3 and 4.
[n] Factors are based on judgment and engineering judgment.

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7.6 LEAD SMELTING

Revised by William M. Vatavuk

7.6.1 Process Description [1-3]

Lead is usually found in nature as a sulfide ore containing small amounts of copper, iron, zinc, and other trace elements. It is normally concentrated at the mine from an ore of 3 to 8 percent lead to an ore concentrate of 55 to 70 percent lead, containing from 13 to 19 percent free and uncombined sulfur by weight.

Normal practice for the production of lead metal from this concentrate involves the following operations (see Figure 7.6-1):

1. Sintering, in which the concentrate lead and sulfur are oxidized to produce lead oxide and sulfur dioxide. (Simultaneously, the charge material, comprised of concentrates, recycle sinter, sand, and other inert materials, is agglomerated to form a dense, permeable material called sinter.)
2. Reducing the lead oxide contained in the sinter to produce molten lead bullion.
3. Refining the lead bullion to eliminate any impurities.

Sinter is produced by means of a sinter machine, a continuous steel pallet conveyor belt moved by gears and sprockets. Each pallet consists of perforated or slotted grates, beneath which are situated windboxes connected to fans that provide a draft on the moving sinter charge. Depending on the direction of this draft, the sinter machine is either of the updraft or downdraft type. Except for the draft direction, however, all machines are similar in design, construction, and operation.

The sintering reaction is autogenous and occurs at a temperature of approximately 1800°F:

$$2\,PbS + 3\,O_2 \rightarrow 2\,PbO + 2\,SO_2 \qquad (1)$$

Operating experience has shown that system operation and product quality are optimum when the sulfur content of the sinter charge is between 5 and 7 percent by weight. To maintain this desired sulfur content, sulfide-free fluxes such as silica and limestone, plus large amounts of recycled sinter and smelter residues are added to the mix. The quality of the product sinter is usually determined by its hardness (Ritter Index), which is inversely proportional to the sulfur content. Hard quality sinter (low sulfur content) is preferred because it resists crushing during discharge from the sinter machine. Conversely, undersized sinter will usually result from insufficient desulfurization and is recycled for further processing.

Of the two kinds of sintering machines used, the updraft design is superior for many reasons. First, the sinter bed height is more permeable (and, hence, can be greater) with an updraft machine, thereby permitting a higher production rate than that of a downdraft machine of similar dimensions. Secondly, the small amounts of elemental lead that form during sintering will solidify at their point of formation with updraft machines; whereas, in downdraft operation, the metal tends to flow downward and collect on the grates or at the bottom of the sinter charge, thus causing increased pressure drop and attendant reduced blower capacity. In addition, the updraft system exhibits the capability of producing sinter of higher lead content and requires less maintenance than the downdraft machine. Finally, and most important from an air pollution control standpoint, updraft sintering can produce a single strong SO_2 effluent stream from the operation, by use of weak gas recirculation. This, in turn, permits the more efficient and economical use of such control methods as sulfuric acid recovery plants.

Lead reduction is carried out in a blast furnace, basically a water-jacketed shaft furnace supported by a refractory base. Tuyeres, through which combustion air is admitted under pressure, are located near the bottom and are evenly spaced on either side of the furnace.

The furnace is charged with a mixture of sinter (60 to 70 percent of charge), metallurgical coke (8 to 14 percent of the charge), and other materials, such as limestone, silica, litharge, slag forming constituents, and various recycled and clean-up materials. In the furnace the sinter is reduced to lead bullion; most of the impurities are

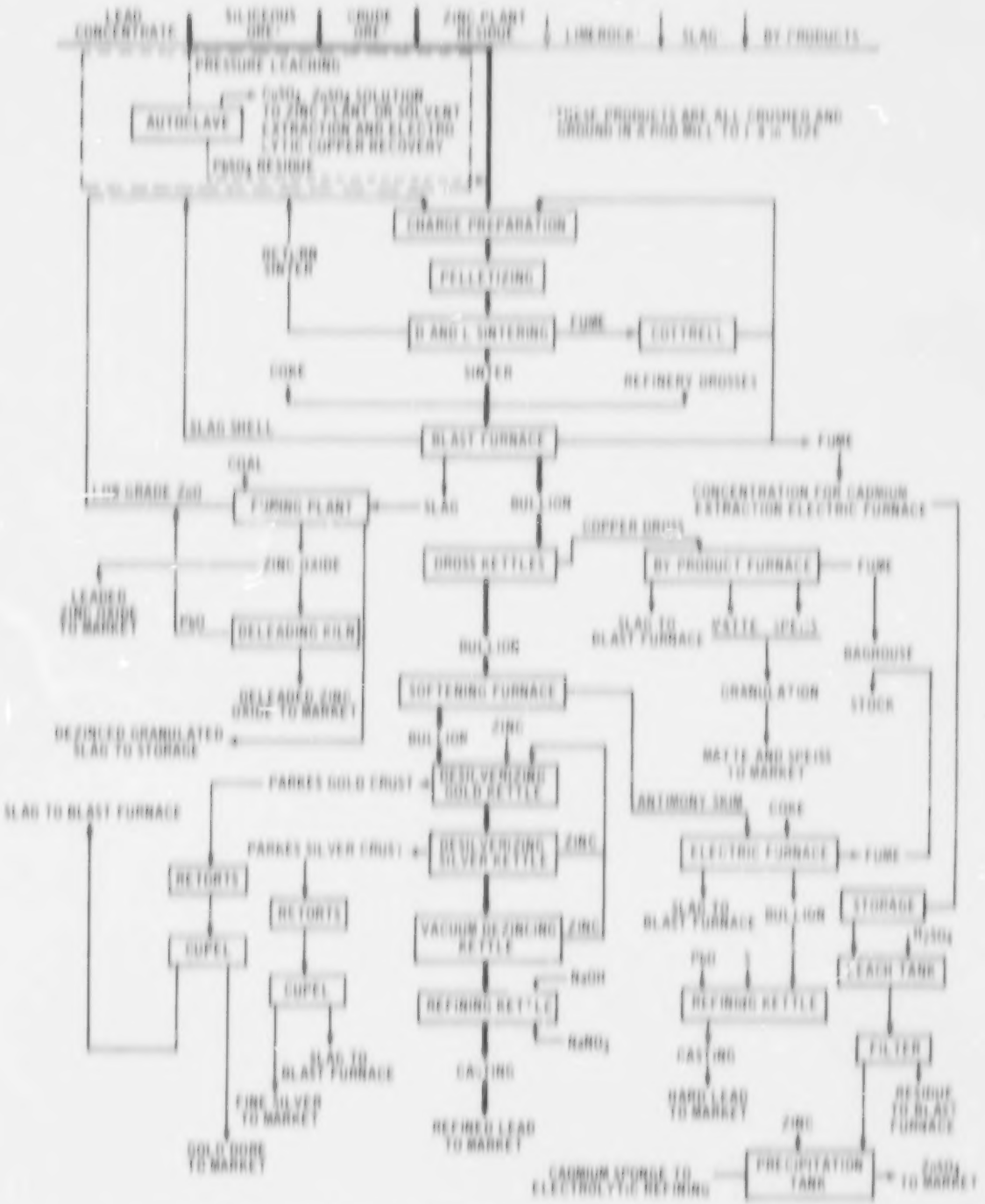

Figure 7.6-1. Typical flowsheet of pyrometallurgical lead smelting.[2]

eliminated in the slag. Solid products from the blast furnace generally separate into four layers: speiss (basically arsenic and antimony, the lightest material), matte (composed of copper sulfide and other metal sulfides), slag (primarily silicates), and lead bullion. The first three layers are combined as slag, which is continually collected from the furnace and either processed at the smelter for its metal content or shipped to treatment facilities.

A certain amount of SO_2 is also generated in blast furnaces due to the presence of small quantities of residual lead sulfide and lead sulfates in the sinter feed. The quantity of these emissions is a function of not only the residual sulfur content in the sinter, but of the amount of sulfur that is captured by copper and other impurities in the slag.

Rough lead bullion from the blast furnace usually requires preliminary treatment (drossing) in steel cast-iron kettles before undergoing refining operations. First, the bullion is cooled to 700 to 800°F; copper and small amounts of sulfur, arsenic, antimony, and nickel are removed from solution and collect on the surface as a dross. This dross, in turn, is treated in a reverberatory-type furnace where the copper and other metal impurities are further concentrated before being routed to copper smelters for their eventual recovery. Drossed lead bullion is further treated for copper removal by the addition of sulfur-bearing material and zinc and/or aluminum to lower the copper content to approximately 0.01 percent.

The final phase of smelting, the refining of the bullion in cast-iron kettles, occurs in five steps:

1. Removal of antimony, tin, and arsenic;
2. Removal of precious metals via the Parke's Process, in which zinc metal combines with gold and silver to form an insoluble intermetallic at operating temperatures;
3. Vacuum removal of zinc;
4. Bismuth removal using the Betterson Process, which involves the addition of calcium and magnesium, which in turn, form an insoluble compound with the bismuth that is skimmed from the kettle; and
5. Removal of remaining traces of metal impurities by addition of NaOH and $NaNO_3$.

The final refined lead, commonly of 99.99 to 99.999 percent purity, is then cast into 100-pound pigs before shipment.

7.6.2 Emissions and Controls [1-3]

Each of the three major lead smelting operations generates substantial quantities of particulates and/or sulfur dioxide.

Nearly 80 percent of the sulfur present in the lead ore concentrate is eliminated in the sintering operation. In handling these process offgases, either a single weak stream is taken from the machine hood at less than 2 percent SO_2 or two streams are taken: one weak stream (<0.5 percent SO_2) from the discharge end of the machine and one strong stream (5 to 7 percent SO_2) taken from the feed end. Single stream operation is generally used when there is little or no market for the recovered sulfur, so that the uncontrolled weak SO_2 stream is emitted to the atmosphere. Where there is a potential sulfur market, however, the strong stream is sent to a sulfuric acid plant, and the weak stream is vented after particulate removal.

When dual gas stream operation is used with updraft sinter machines, the weak gas stream can be recirculated through the bed to mix with the strong gas stream, resulting in a single stream with an SO_2 concentration of about 6 percent. This technique has the overall effect of decreasing machine production capacity, but does permit a more convenient and economical recovery of the SO_2 via sulfuric acid plants and other control methods.

Without weak gas recirculation, the latter portion of the sinter machine acts as a cooling zone for the sinter and consequently assists in the reduction of dust formation during product discharge and screening. However,

when recirculation is used, the sinter is usually discharged in a relatively hot state (400 to 500°C), with an attendant increase in particulate formation. Methods for reducing these dust quantities include recirculation of off-gases through the sinter bed, relying upon the filtering effect of the latter, or ducting the gases from the discharge through a particulate collection device directly to the atmosphere. Because reaction activity has ceased in the discharge area in these cases, these latter gases contain little SO_2.

The particulate emissions from sinter machines consist of from 5 to 20 percent of the concentrated ore feed. When expressed in terms of product weight, these emissions are an estimated 106.5 kg/MT (213 lb/ton) of lead produced. This value, along with other particulate and SO_2 factors, appears in Table 7.6-1.

Table 7.6-1. EMISSION FACTORS FOR PRIMARY LEAD SMELTING PROCESSES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Process	Particulates		Sulfur dioxide	
	kg/MT	lb/ton	kg/MT	lb/ton
Ore crushing[b]	1.0	2.0	--	--
Sintering (updraft)[c]	106.5	213.0	275.0	550.0
Blast furnace[d]	180.5	361.0	22.5	45.0
Dross reverberatory furnace[d]	10.0	20.0	Neg	Neg
Materials handling[d]	2.5	5.0	--	--

[a]Ore crushing emission factors expressed as kg/MT (lb/ton) of crushed ore; all other emission factors expressed as kg/MT (lb/ton) of lead product.
[b]Reference 2.
[c]References 1, 4, 5, and 6.
[d]References 1, 2, and 7.

Typical material balances from domestic lead smelters indicate that about 10 to 20 percent of the sulfur in the ore concentrate fed to the sinter machine is eliminated in the blast furnace. However, only *half* of this amount (about 7 percent of the total) is emitted as SO_2; the remainder is captured by the slag. The concentration of this SO_2 stream can vary from 500 to 2500 ppm by volume, depending on the amount of dilution air injected to oxidize the carbon monoxide and cool the stream before baghouse treatment for particulate removal.

Particulate emissions from blast furnaces contain many different kinds of material, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic, and other metals-containing compounds associated with lead ores. These particles readily agglomerate, are primarily submicron in size, difficult to wet, cohesive, and will bridge and arch in hoppers. On the average, this dust loading is quite substantial (see Table 7.6-1).

Virtually no sulfur dioxide emissions are associated with the various refining operations. However, a small amount of particulates is generated by the dross reverberatory furnace (10 kg/MT of lead).

Finally, minor quantities of particulates are generated by ore crushing and materials handling operations. These emission factors are also presented in Table 7.6-1.

Methods used to control emission from lead smelter operations fall into two broad categories: particulate and sulfur dioxide control techniques. The most commonly employed high efficiency particulate control devices are fabric filters and electrostatic precipitators, which, in turn, often follow centrifugal collectors and tubular coolers (pseudogravity collectors). Three of the six lead smelters presently operating in the United States use single absorption sulfuric acid plants for control of sulfur dioxide emissions from sinter machines and, occasionally, blast furnaces. Other technically feasible SO_2 control methods are elemental sulfur recovery plants and

dimethylaniline (DMA) and ammonia absorption processes. These methods and their representative control efficiencies are listed in Table 7.6-2.

Table 7.6-2. EFFICIENCIES OF REPRESENTATIVE CONTROL DEVICES USED WITH PRIMARY LEAD SMELTING OPERATIONS

Control device or method	Control device efficiency range	
	Particulates	Sulfur dioxide
Centrifugal collector (e.g., cyclone)[a]	80 to 90	--
Electrostatic precipitator[a]	95 to 99	--
Fabric filter[a]	95 to 99	--
Tubular cooler (associated with waste heat boiler)[a]	70 to 80	--
Sulfuric acid plant (single contact)[b,c]	99.5 to 99.9	95 to 97
Elemental sulfur recovery plant[b,d]	--	90
Dimethylaniline (DMA) absorption process[b,e]	--	95 to 98.8
Ammonia absorption process[b,f]	--	92 to 96.9

[a]Reference 2.
[b]Reference 1.
[c]High particulate control efficiency due to action of acid plant gas precleaning system. Range of SO_2 efficiencies based on inlet and outlet concentrations of 5 to 7 percent and 2000 ppm, respectively.
[d]Collection efficiency for a two stage, uncontrolled Claus type plant. Refer to Section 5.18 for more information.
[e]Range of SO_2 efficiencies based on inlet and outlet concentrations of 4 to 6 percent and 500 to 3000 ppm, respectively.
[f]Range of SO_2 efficiencies based on inlet and outlet concentrations of 1.5 to 2.5 percent and 1200 ppm, respectively.

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7.7 ZINC SMELTING

7.7.1 Process Description[1-3]

As stated previously, most domestic zinc comes from zinc and lead ores. Another important source of raw material for zinc metal has been zinc oxide from fuming furnaces. For efficient recovery of zinc, sulfur must be removed from concentrates to a level of less than 2 percent. This is done by fluidized beds or multiple-hearth roasting occasionally followed by sintering. Metallic zinc can be produced from the roasted ore by the horizontal or vertical retort process or by the electrolytic process if a high-purity zinc is needed.

7.7.2 Emissions and Controls[1-3]

Dust, fumes, and sulfur dioxide are emitted from zinc concentrate roasting or sintering operations. Particulates may be removed by electrostatic precipitators or baghouses. Sulfur dioxide may be converted directly into sulfuric acid or vented. Emission factors for zinc smelting are presented in Table 7.7-1.

Table 7.7-1. EMISSION FACTORS FOR PRIMARY ZINC SMELTING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Type of operation	Particulates		Sulfur oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Roasting (multiple hearth)[b]	120	60	1100	550
Sintering[c]	90	45	d	d
Horizontal retorts[c]	8	4	--	--
Vertical retorts[c]	100	50	--	--
Electrolytic process	3	1.5	--	--

[a]Approximately 2 unit weights of concentrated ore are required to produce 1 unit weight of zinc metal. Emission factors expressed as units per unit weight of concentrated ore produced.
[b]References 3 and 4.
[c]References 2 and 3.
[d]Included in SO_2 losses from roasting.
[e]Reference 3.

References for Section 7.7

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7.8 SECONDARY ALUMINUM OPERATIONS

7.8.1 Process Description[1-2]

Secondary aluminum operations involve making lightweight metal alloys for industrial castings and ingots. Copper, magnesium, and silicon are the most common alloying constituents. Aluminum alloys for castings are melted in small crucible furnaces charged by hand with pigs and foundry returns. Larger melting operations use open-hearth reverberatory furnaces charged with the same type of materials but by mechanical means. Small operations sometimes use sweating furnaces to treat dirty scrap in preparation for smelting.

To produce a high-quality aluminum product, fluxing is practiced to some extent in all secondary aluminum melting. Aluminum fluxes are expected to remove dissolved gases and oxide particles from the molten bath. Sodium and various mixtures of potassium or sodium chloride with cryolite and chlorides of aluminum, zinc, or are used as fluxes. Chlorine gas is usually lanced into the molten bath to reduce the magnesium content by reacting to form magnesium and aluminum chlorides.[1-2]

7.8.2 Emissions[2]

Emissions from secondary aluminum operations include fine particulate matter and gaseous chlorine. A large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clean, large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems. Table 7.8-1 presents particulate emission factors for secondary aluminum operations.

Table 7.8-1. PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS[a]
EMISSION FACTOR RATING: B

Type of operation	Uncontrolled		Baghouse		Electrostatic precipitator	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Sweating furnace	14.5	7.25	3.3	1.65	–	–
Smelting						
Crucible furnace	1.9	0.95	–	–	–	–
Reverberatory furnace	4.3	2.15	1.3	0.65	1.3	0.65
Chlorination station[b]	1000	500	50	25	–	–

[a]Reference 5. Emission factors expressed as units per unit weight of metal processed.
[b]Pounds per ton (kg/MT) of chlorine used.

References for Section 7.8

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7.9 BRASS AND BRONZE INGOTS (COPPER ALLOYS)

7.9.1 Process Description[1]

Obsolete domestic and industrial copper-bearing scrap is the basic raw material of the brass and bronze ingot industry. The scrap frequently contains any number of metallic and nonmetallic impurities, which can be removed by such methods as hand sorting, magnetizing, heat methods such as sweating or burning, and gravity separation in a water medium.

Brass and bronze ingots are produced from a number of different furnaces through a combination of melting, smelting, refining, and alloying of the processed scrap material. Reverberatory, rotary, and crucible furnaces are the ones most widely used, and the choice depends on the size of the melt and the alloy desired. Both the reverberatory and the rotary furnaces are normally heated by direct firing, in which the flame and gases come into direct contact with the melt. Processing is essentially the same in any furnace except for the differences in the types of alloy being handled. Crucible furnaces are usually much smaller and are used principally for special-purpose alloys.

7.9.2 Emissions and Controls[1]

The principal source of emissions in the brass and bronze ingot industry is the refining furnace. The exit gas from the furnace may contain the normal combustion products such as fly ash, soot, and smoke. Appreciable amounts of zinc oxide are also present in this exit gas. Other sources of particulate emissions include the preparation of raw materials and the pouring of ingots.

The only air pollution control equipment that is generally accepted in the brass and bronze ingot industry is the baghouse filter, which can reduce emissions by as much as 99.9 percent. Table 7.9-1 summarizes uncontrolled emissions from various brass and bronze melting furnaces.

Table 7.9-1. PARTICULATE EMISSION FACTORS FOR BRASS AND BRONZE MELTING FURNACES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: A

Type of furnace	Uncontrolled emissions[b]	
	lb/ton	kg/MT
Blast[c]	18	9
Crucible	12	6
Cupola	73	36.5
Electric induction	2	1
Reverberatory	70	35
Rotary	60	30

[a]Reference 1. Emission factors expressed as units per unit weight of metal charged.
[b]The use of a baghouse can reduce emissions by 95 to 99.5 percent.
[c]Represents emissions following precleaner.

Reference for Section 7.9

1. Air Pollution Aspects of Brass and Bronze Smelting and Refining Industry. U. S. DHEW, PHS, EHS, National Air Pollution Control Administration. Raleigh, N. C. Publication Number AP-58. November 1969.

7.10 GRAY IRON FOUNDRY

7.10.1 Process Description[1]

Three types of furnaces are used to produce gray iron castings: cupolas, reverberatory furnaces, and electric induction furnaces. The cupola is the major source of molten iron for the production of castings. In operation, a bed of coke is placed over the sand bottom in the cupola. After the bed of coke has begun to burn properly, alternate layers of coke, flux, and metal are charged into the cupola. Combustion air is forced into the cupola, causing the coke to burn and melt the iron. The molten iron flows out through a taphole.

Electric furnaces are commonly used where special alloys are to be made. Pig iron and scrap iron are charged to the furnace and melted, and alloying elements and fluxes are added at specific intervals. Induction furnaces are used where high-quality, clean metal is available for charging.

7.10.2 Emissions[1]

Emissions from cupola furnaces include gases, dust, fumes, and smoke and oil vapors. Dust arises from dirt on the metal charge and from fines in the coke and limestone charge. Smoke and oil vapor arise primarily from the partial combustion and distillation of oil from greasy scrap charged to the furnace. Also, the effluent from the cupola furnace has a high carbon monoxide content that can be controlled by an afterburner. Emissions from reverberatory and electric induction furnaces consist primarily of metallurgical fumes and are relatively low. Table 7.10-1 presents emission factors for the manufacture of iron castings.

Table 7.10-1. EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a,b,c]

EMISSION FACTOR RATING: B

Type of furnace	Particulates		Carbon monoxide	
	lb/ton	kg/MT	lb/ton	kg/MT
Cupola				
Uncontrolled	17	8.5	145[c,d]	72.5[c,d]
Wet cap	8	4	–	–
Impingement scrubber	5	2.5	–	–
High energy scrubber	0.8	0.4	–	–
Electrostatic precipitator	0.6	0.3	–	–
Baghouse	0.2	0.1	–	–
Reverberatory	2	1	–	–
Electric induction	1.5	0.75	–	–

[a]References 2 through 5. Emission factors expressed as units per unit weight of metal charged.

[b]Approximately 85 percent of the total charge is metal. For every unit weight of coke in the charge, 7 unit weights of gray iron are produced.

[c]Reference 6.

[d]A well-designed afterburner can reduce emissions to 9 pounds per ton (4.6 kg/MT) of metal charged.[7]

References for Section 7.10

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7.11 SECONDARY LEAD SMELTING

Revised by William M. Vatavuk

7.11.1 Process Description [1-3]

In the secondary smelting, refining, and alloying of lead, the three types of furnace most commonly used are reverberatory, blast or cupola, and pot. The grade of metal to be produced—soft, semisoft, or hard—dictates the type of furnace to be used.

Used for the production of semisoft lead, the reverberatory furnace reclaims this metal from a charge of lead scrap, battery plates, oxides, drosses, and lead residues. The furnace consists of an outer shell built in the shape of a rectangular box lined with refractory brick. To provide heat for melting, the charge gas or oil-fired burners are usually placed at one end of the furnace, and the material to be melted is charged through an opening in the shell.

The charge is placed in the furnace in such a manner as to keep a small mound of unmelted material on top of the bath. Continuously, as this mound becomes molten at the operating temperature (approximately 1250°C), more material is charged. Semisoft lead is tapped off periodically as the level of the metal rises in the furnace. The amount of metal recovered is about 50 to 60 kilograms per square meter of hearth area per hour.

A similar kind of furnace—the revolving (rotary) reverberatory—is used at several European installations for the recovery of lead from battery scrap and lead sulfate sludge. Its charge makeup and operating characteristics are identical to the reverberatories used in the United States, except that the furnace slowly revolves as the charge is heated.

The blast (cupola) furnace, used to produce "hard" lead, is normally charged with the following: remelt slag from previous runs (48.5 percent); cast iron scrap (4.5 percent); limestone (3 percent); coke (15.5 percent); and drosses from pot furnace refining, oxides, and reverberatory slag (28.5 percent). Similar to an iron cupola, the furnace consists of a steel sheet lined with refractory material. Air, under high pressure, is introduced at the bottom through tuyeres to permit combustion of the coke, which provides the heat and a reducing atmosphere.

As the charge material melts, limestone and iron form an oxidation-retardant flux that floats to the top, and the molten lead flows from the furnace into a holding pot at a nearly continuous rate. The rest (30 percent) of the tapped, molten material is slag, 5 percent of which is retained for later remelt. From the holding pot, the lead is usually cast into large ingots called "buttons" or "sows."

Pot-type furnaces are used for remelting, alloying, and refining processes. These furnaces are usually gas fired and range in size from 1 to 45 metric tons capacity. Their operation consists simply of charging ingots of lead or alloy material and firing the charge until the desired product quality is obtained.

Refining processes most commonly employed are those for the removal of copper and antimony to produce soft lead, and those for the removal of arsenic, copper, and nickel to produce hard lead.

Figure 7.11-1 illustrates these three secondary lead smelting processes.

7.11.2 Emissions and Controls [1-3]

The emissions and controls from secondary lead smelting processes may be conveniently considered according to the type of furnace employed.

With the reverberatory furnaces, the temperature maintained is high enough to oxidize the sulfides present in the charge to sulfur dioxide and sulfur trioxide, which, in turn, are emitted in the exit gas. Also emitted are such particulates (at concentrations of 16 to 50 grams per cubic meter) as oxides, sulfides, and sulfates of lead, tin,

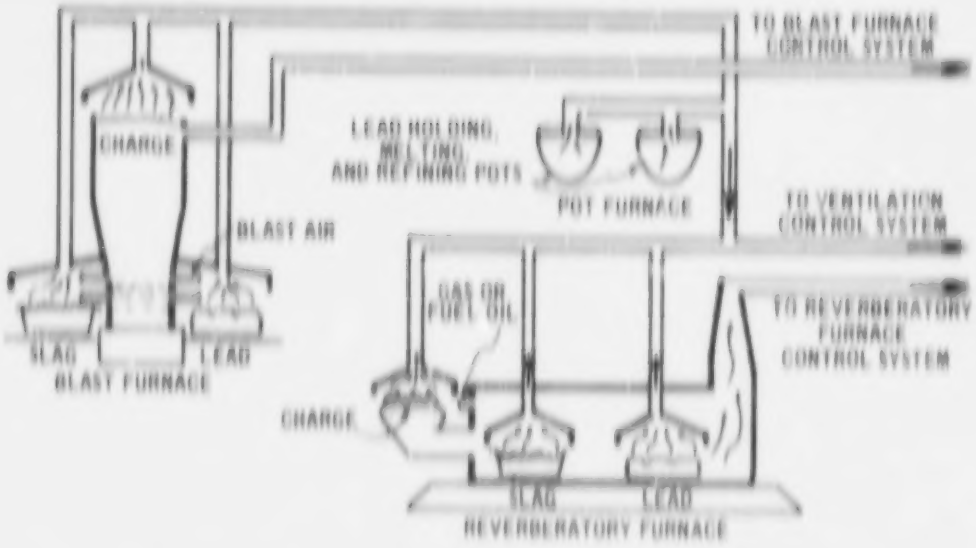

Figure 7.11-1. Secondary lead smelter processes.[4]

arsenic, copper, and antimony. The particles are nearly spherical and tend to agglomerate. Emission factors for reverberatory furnaces are presented in Table 7.11-1.

The most practical control system for a reverberatory furnace consists of a gas settling/cooling chamber and a fabric filter. This system effects a particulate removal of well in excess of 99 percent. Because of the potential presence of sparks and flammable material, a great deal of care is taken to control the temperature of the gas stream. In turn, the type of filter cloth selected depends upon stream temperature and such parameters as gas

Table 7.11-1. EMISSION FACTORS FOR SECONDARY LEAD SMELTING FURNACES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Furnace type	Particulates		Sulfur dioxide	
	kg/MT	lb/ ton	kg/MT	lb/ton
Reverberatory[b]	73.5 (28.0 to 156.5)[c]	1.17 (56 to 313)	40.0 (35.5 to 44.0)	80 (71 to 88)
Blast (cupola)[d]	96.5 (10.5 to 190.5)	193 (21.0 to 381.0)	26.5 (9.0 to 55.0)	53.0 (18 to 110)
Pot[e]	0.4	0.8	Neg	Neg
Rotary reverb.rotary[f]	35.0	70.0	NA[g]	NA[g]

[a]All emission factors expressed in terms of kg/MT and lb/ton of metal charged to furnace.
[b]References 2, 5 through 7.
[c]Numbers in parentheses represent ranges of values obtained.
[d]References 2, 7 through 9.
[e]Reference 7.
[f]Reference 9.
[g]NA – no data available to make estimates.

stream corrosivity and the permeability and abrasion (or stress)-resisting characteristics of the cloth. In any case, the filtering velocity seldom exceeds 0.6 m/min. Table 7.11-2 offers a listing of control devices and their efficiencies.

Table 7.11-2. EFFICIENCIES OF PARTICULATE CONTROL EQUIPMENT ASSOCIATED WITH SECONDARY LEAD SMELTING FURNACES

Control device	Furnace type	Particulate control efficiency
Fabric filter[a]	Blast	98.4
	Reverberatory	99.2
Dry cyclone plus fabric filter[a]	Blast	99.0
Wet cyclone plus fabric filter[b]	Reverberatory	99.7
Settling chamber plus dry cyclone plus fabric filter[c]	Reverberatory	99.8
Venturi scrubber plus demister[d]	Blast	99.1

[a]Reference 3.
[b]Reference 5.
[c]Reference 6.
[d]Reference 8.

Combustion air from the tuyeres passing through the blast furnace charge conveys metal oxides, ash of coke, and other particulates present in the charge. The particulate is roughly 7 percent by weight of the total charge (up to 44 g/m^3). In addition to particulates, the stack gases also contain carbon monoxide. However, the carbon monoxide and any volatile hydrocarbons present are oxidized to carbon dioxide and water in the upper portion of the furnace, which effectively acts as an afterburner.

Fabric filters, preceded by radiant cooling columns, evaporative water coolers, or air dilution jets, are also used to control blast furnace particulates. Overall efficiencies exceeding 95 percent are common (see Table 7.11-2). Representative size distributions of particles in blast and reverberatory furnace streams are presented in Table 7.11-3.

Compared with the other furnace types, pot furnace emissions are low (see Table 7.11-1). However, to maintain a hygienic working environment, pot furnace off gases, usually along with emission streams from other furnaces, are directed to fabric filter systems.

Table 7.11-3. REPRESENTATIVE PARTICLE SIZE DISTRIBUTION FROM A COMBINED BLAST AND REVERBERATORY FURNACE GAS STREAM[a]

Size range, μm	Fabric filter catch, wt %
0 to 1	13.3
1 to 2	45.2
2 to 3	19.1
3 to 4	14.0
4 to 16	8.4

[a]Reference 1.
[b]These particles are distributed log normally, according to the following frequency distribution:

$$\frac{dG}{d\log D_p} = 1.66 \exp\left[\frac{-(\log D_p - 0.282)^2}{0.131}\right]$$

References for Section 7.11

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7. Particulate Pollutant Systems Study, Vol. I. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Office of Air and Water Programs, Research Triangle Park, N.C. May 1971.

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9. Source Testing Report: Secondary Lead Plant Stack Emission Sampling. Battelle Columbus Laboratories, Columbus, Ohio. Prepared for Environmental Protection Agency, Office of Air and Water Programs, Research Triangle Park, N.C. Report Number 71-CI-34. July 1972.

7.12 SECONDARY MAGNESIUM SMELTING

7.12.1 Process Description[1]

Magnesium smelting is carried out in crucible or pot-type furnaces that are charged with magnesium scrap and fired by gas, oil, or electric heating. A flux is used to cover the surface of the molten metal because magnesium will burn in air at the pouring temperature (approximately 1500°F or 815°C). The molten magnesium, usually cast by pouring into molds, is annealed in ovens utilizing an atmosphere devoid of oxygen.

7.12.2 Emissions[1]

Emissions from magnesium smelting include particulate magnesium (MgO) from the melting, nitrogen oxides from the fixation of atmospheric nitrogen by the furnace temperatures, and sulfur dioxide losses from annealing oven atmospheres. Factors affecting emissions include the capacity of the furnace; the type of flux used on the molten material; the amount of fluxing used; the amount of contamination of the scrap, including oil and other hydrocarbons; and the type and extent of control equipment used on the process. The emission factors for a pot furnace are shown in Table 7.12-1.

Table 7.12-1. EMISSION FACTORS FOR MAGNESIUM SMELTING
EMISSION FACTOR RATING: C

Type of furnace	Particulates[a] lb/ton	Particulates[a] kg/MT
Pot furnace		
Uncontrolled	4	2
Controlled	0.4	0.2

[a]References 2 and 3. Emission factors expressed as units per unit weight of metal processed.

References for Section 7.13

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7.13 STEEL FOUNDRIES

7.13.1 Process Description[1]

Steel foundries produce steel castings by melting steel metal and pouring it into molds. The melting of steel for castings is accomplished in one of five types of furnaces: direct electric arc, electric induction, open-hearth, crucible, and pneumatic converter. The crucible and pneumatic converter are not in widespread use, so this section deals only with the remaining three types of furnaces. Raw materials supplied to the various melting furnaces include steel scrap of all types, pig iron, ferroalloys, and limestone. The basic melting process operations are furnace charging, melting, tapping the furnace into a ladle, and pouring the steel into molds. An integral part of the steel foundry operation is the preparation of casting molds, and the shakeout and cleaning of these castings. Some common materials used in molds and cores for hollow casting include sand, oil, clay, and resin. Shakeout is the operation by which the cool casting is separated from the mold. The castings are commonly cleaned by shot blasting, and surface defects such as fins are removed by burning and grinding.

7.13.2 Emissions[1]

Particulate emissions from steel foundry operations include iron oxide fumes, sand fines, graphite, and metal dust. Gaseous emissions from foundry operations include oxides of nitrogen, oxides of sulfur, and hydrocarbons. Factors affecting emissions from the melting process include the quality and cleanliness of the scrap and the amount of oxygen lancing. The concentrations of oxides of nitrogen are dependent upon operating conditions in the melting unit, such as temperature and the rate of cooling of the exhaust gases. The concentration of carbon monoxide in the exhaust gases is dependent on the amount of draft on the melting furnace. Emissions from the shakeout and cleaning operations, mostly particulate matter, vary according to type and efficiency of dust collection. Gaseous emissions from the mold and baking operations are dependent upon the fuel used by the ovens and the temperature reached in these ovens. Table 7.13-1 summarizes the emission factors for steel foundries.

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Table 7.13-1. EMISSION FACTORS FOR STEEL FOUNDRIES
EMISSION FACTOR RATING: A

Type of process	Particulates[a]		Nitrogen oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Melting				
Electric arc[b,c]	13 (4 to 40)	6.5 (2 to 20)	0.2	0.1
Open hearth[d,e]	11 (2 to 20)	5.5 (1 to 10)	0.01	0.005
Open hearth oxygen lanced[f,g]	10 (8 to 11)	5 (4 to 5.5)	--	--
Electric induction[h]	0.1	0.05	--	--

[a]Emission factors expressed as units per unit weight of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range.

[b]Electrostatic precipitator, 92 to 96 percent control efficiency; baghouse (fabric filter), 98 to 99 percent control efficiency; venturi scrubber, 94 to 98 percent control efficiency.

[c]References 2 through 11.

[d]Electrostatic precipitator, 95 to 98.5 percent control efficiency; baghouse, 99.9 percent control efficiency; venturi scrubber, 96 to 99 percent control efficiency.

[e]References 2 and 12 through 14.

[f]Electrostatic precipitator, 95 to 98 percent control efficiency; baghouse, 99 percent control efficiency; venturi scrubber, 95 to 98 percent control efficiency.

[g]References 7 and 15.

[h]Usually not controlled.

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7.14 SECONDARY ZINC PROCESSING

7.14.1 Process Description[1]

Zinc processing includes zinc reclaiming, zinc oxide manufacturing, and zinc galvanizing. Zinc is separated from scrap containing lead, copper, aluminum, and iron by careful control of temperature in the furnace, allowing each metal to be removed at its melting range. The furnaces typically employed are the pot, muffle, reverberatory, or electric induction. Further refining of the zinc can be done in retort distilling or vaporization furnaces where the vaporized zinc is condensed to the pure metallic form. Zinc oxide is produced by distilling metallic zinc into a dry air stream and capturing the subsequently formed oxide in a baghouse. Zinc galvanizing is carried out in a vat or in bath-type dip tanks utilizing a flux cover. Iron and steel pieces to be coated are cleaned and dipped into the vat through the covering flux.

7.14.2 Emissions[1]

A potential for particulate emissions, mainly zinc oxide, occurs if the temperature of the furnace exceeds 1100°F (595°C). Zinc oxide (ZnO) may escape from condensers or distilling furnaces, and because of its extremely small particle size (0.03 to 0.5 micron), it may pass through even the most efficient collection systems. Some loss of zinc oxides occurs during the galvanizing processes, but these losses are small because of the flux cover on the bath and the relatively low temperature maintained in the bath. Some emissions of particulate ammonium chloride occur when galvanized parts are dusted after coating to improve their finish. Another potential source of emissions of particulates and gaseous zinc is the tapping of zinc-vaporizing muffle furnaces to remove accumulated slag residue. Emissions of carbon monoxide occur when zinc oxide is reduced by carbon. Nitrogen oxide emissions are also possible because of the high temperature associated with the smelting and the resulting fixation of atmospheric nitrogen. Table 7.14-1 summarizes the emission factors from zinc processing.

Table 7.14-1. PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC SMELTING[a]
EMISSION FACTOR RATING: C

Type of furnace	Emissions	
	lb/ton	kg/MT
Retort reduction	47	23.5
Horizontal muffle	45	22.5
Pot furnace	0.1	0.05
Kettle sweat furnace processing[b]		
Clean metallic scrap	Neg	Neg
General metallic scrap	11	5.5
Residual scrap	25	12.5
Reverberatory sweat furnace processing[b]		
Clean metallic scrap	Neg	Neg
General metallic scrap	13	6.5
Residual scrap	32	16
Galvanizing kettles	5	2.5
Calcining kiln	89	44.5

[a]References 2 through 4. Emission factors expressed as units per unit weight of metal produced.
[b]Reference 5.

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8. MINERAL PRODUCTS INDUSTRY

This section involves the processing and production of various minerals. Mineral processing is characterized by particulate emissions in the form of dust. Frequently, as in the case of crushing and screening, this dust is identical to the material being handled. Emissions also occur through handling and storing the finished product because this material is often dry and fine. Particulate emissions from some of the processes such as quarrying, yard storage, and dust from transport are difficult to control. Most of the emissions from the manufacturing processes discussed in this section, however, can be reduced by conventional particulate control equipment such as cyclones, scrubbers, and fabric filters. Because of the wide variety in processing equipment and final product, emissions cover a wide range; however, average emission factors have been presented for general use.

8.1 ASPHALTIC CONCRETE PLANTS

Revised by Dennis H. Ackerson and James H. Southerland

8.1.1 Process Description

Selecting and handling the raw material is the first step in the production of asphaltic concrete, a paving substance composed of a combination of aggregates uniformly mixed and coated with asphalt cement. Different applications of asphaltic concrete require different aggregate size distributions, so that the raw aggregates are crushed and screened at the quarries. The coarse aggregate usually consists of crushed stone and gravel, but waste materials, such as slag from steel mills or crushed glass, can be used as raw material.

Plants produce finished asphaltic concrete through either batch (Figure 8.1-1) or continuous (Figure 8.1-2) aggregate mixing operations. The raw aggregate is normally stockpiled near the plant at a location where the moisture content will stabilize between 3 and 5 percent by weight.

As processing for either type of operation begins, the aggregate is hauled from the storage piles and placed in the appropriate hoppers of the cold-feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas- or oil-fired rotary dryer. Because a substantial portion of the heat is transferred by radiation, dryers are equipped with flights that are designed to tumble the aggregate and promote drying.

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified by size into as many as four different grades. At this point it enters the mixing operation.

In a batch plant, the classified aggregate drops into one of four large bins. The operator controls the aggregate size distribution by opening individual bins and allowing the classified aggregate to drop into a weigh hopper until the desired weight is obtained. After all the material is weighed out, the sized aggregates are dropped into a mixer and mixed dry for about 10 seconds. The asphalt, which is a solid at ambient temperatures, is pumped from heated storage tanks, weighed, and then injected into the mixer. The hot, mixed batch is then dropped into a truck and hauled to the job site.

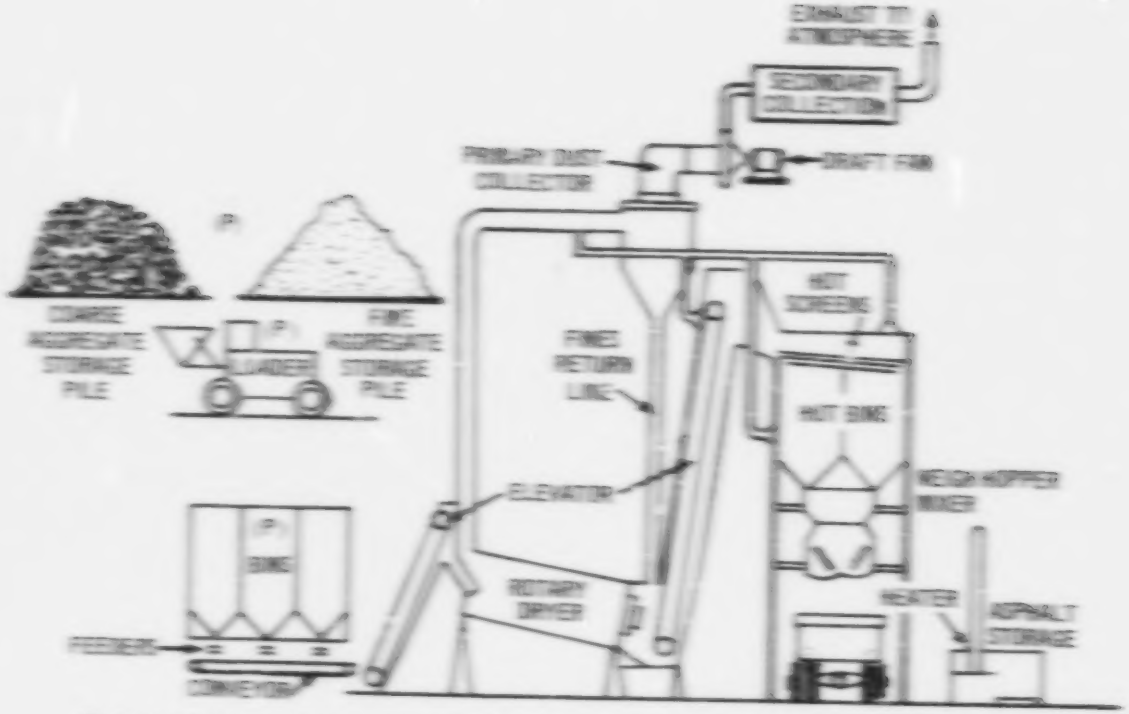

Figure 8.1-1. Batch hot-mix asphalt plant. "P" denotes particulate emission points.[1]

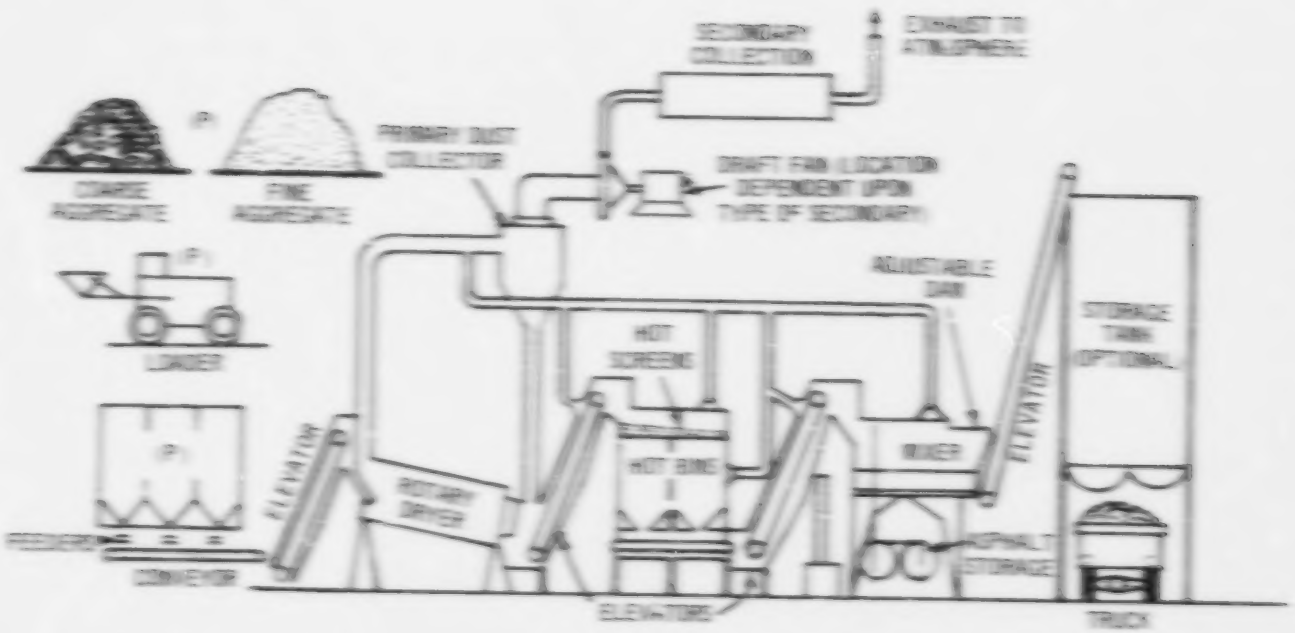

Figure 8.1-2. Continuous hot-mix asphalt plant. "P" denotes particulate emission points.[1]

In a continuous plant, the classified aggregate drops into a set of small bins, which collect and meter the classified aggregate to the mixer. From the hot bins, the aggregate is metered through a set of feeder conveyors to another bucket elevator and into the mixer. Asphalt is metered into the inlet end of the mixer, and retention time is controlled by an adjustable dam at the end of the mixer. The mix flows out of the mixer into a hopper from which the trucks are loaded.

8.1.2 Emissions and Controls[1-4]

Dust sources are the rotary dryer; the hot aggregate elevators; the vibrating screens; and the hot-aggregate storage bins, weigh hoppers, mixers, and transfer points. The largest dust emission source is the rotary dryer. In some plants, the dust from the dryer is handled separately from emissions from the other sources. More commonly, however, the dryer, its vent lines, and other fugitive sources are treated in combination by a single collector and fan system.

The choice of applicable control equipment ranges from dry, mechanical collectors to scrubbers and fabric collectors; attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment, such as large diameter cyclone, skimmer, or settling chambers. These chambers are often used as classifiers with the collected materials being returned to the hot aggregate elevator to combine with the dryer aggregate load. The air discharge from the primary collector is seldom vented to the atmosphere because high emission levels would result. The primary collector effluent is therefore ducted to a secondary or even to a tertiary collection device.

Emission factors for asphaltic concrete plants are presented in Table 8.1-1. Particle size information has not been included because the particle size distribution varies with the aggregate being used, the mix being made, and the type of plant operation.

Table 8.1-1. PARTICULATE EMISSION FACTORS FOR ASPHALTIC CONCRETE PLANTS[a]
EMISSION FACTOR RATING: A

Type of control	Emissions	
	lb/ton	kg/MT
Uncontrolled[b]	45.0	22.5
Precleaner	15.0	7.5
High efficiency cyclone	1.7	0.85
Spray tower	0.4	0.20
Multiple centrifugal scrubber	0.3	0.15
Baffle spray tower	0.3	0.15
Orifice type scrubber	0.04	0.02
Baghouse[c]	0.1	0.05

[a] References 1, 2, and 5 through 10.
[b] Almost all plants have at least a precleaner following the rotary dryer.
[c] Emissions from a properly designed, installed, operated, and maintained collector can be as low as 0.005 to 0.020 lb/ton (0.0025 to 0.010 kg/MT).

References for Section 8.1

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5. Air Pollution Engineering Manual. Air Pollution Control District, County of Los Angeles. U.S. DHEW, Public Health Service. PHS Publication Number 999-AP-40. 1967.

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8.2 ASPHALT ROOFING

8.2.1 Process Description[1]

The manufacture of asphalt roofing felts and shingles involves saturating fiber media with asphalt by means of dipping and/or spraying. Although it is not always done at the same site, preparation of the asphalt saturant is an integral part of the operation. This preparation, called "blowing," consists of oxidizing the asphalt by bubbling air through the liquid asphalt for 8 to 16 hours. The saturant is then transported to the saturation tank or spray area. The saturation of the felts is accomplished by dipping, high pressure sprays, or both. The final felts are made in various weights: 15, 30, and 55 pounds per 100 square feet (0.72, 1.5, and 2.7 kg/m^2). Regardless of the weight of the final product, the makeup is approximately 40 percent dry felt and 60 percent asphalt saturant.

8.2.2 Emissions and Controls[1]

The major sources of particulate emissions from asphalt roofing plants are the asphalt blowing operations and the felt saturation. Another minor source of particulates is the covering of the roofing material with roofing granules. Gaseous emissions from the saturation process have not been measured but are thought to be slight because of the initial driving off of contaminants during the blowing process.

A common method of control at asphalt saturating plants is the complete enclosure of the spray area and saturator with good ventilation through one or more collection devices, which include combinations of wet scrubbers and two-stage low-voltage electrical precipitators, or cyclones and fabric filters. Emission factors for asphalt roofing are presented in Table 8.2-1.

Table 8.2-1. EMISSION FACTORS FOR ASPHALT ROOFING MANUFACTURING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: D

Operation	Particulate[b]		Carbon monoxide		Hydrocarbons (CH_4)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Asphalt blowing[c]	2.5	1.25	0.9	0.45	1.5	0.75
Felt saturation[d]						
Dipping only	1	0.5	–	–	–	–
Spraying only	3	1.5	–	–	–	–
Dipping and spraying	2	1	–	–	–	–

[a] Approximately 0.66 unit of asphalt input is required to produce 1 unit of saturated felt. Emission factors expressed as units per unit weight of saturated felt produced.

[b] Low voltage precipitators can reduce emissions by about 60 percent; when they are used in combination with a scrubber, overall efficiency is about 85 percent.

[c] Reference 3.

[d] References 3 and 4.

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8.3 BRICKS AND RELATED CLAY PRODUCTS

Revised by Dennis H. Ackerson

8.3.1 Process Description

The manufacture of brick and related products such as clay pipe, pottery, and some types of refractory brick involves the mining, grinding, screening, and blending of the raw materials, and the forming, curing or shaping, drying or curing, and firing of the final product.

Surface clays and shales are mined in open pits; most fine clays are found underground. After mining, the material is crushed to remove stones and stirred before it passes onto screens that are used to segregate the particles by size.

At the start of the forming process, clay is mixed with water, usually in a pug mill. The three principal processes for forming brick are: stiff-mud, soft-mud, and dry-process. In the stiff-mud process, sufficient water is added to give the clay plasticity; bricks are then formed by forcing the clay through a die and using cutter wire to separate the bricks. All structural tile and most brick are formed by this process. The soft-mud process is usually used when the clay contains too much water for the stiff-mud process. The clay is mixed with water until the moisture content reaches 20 to 30 percent, and the bricks are formed in molds. In the dry-press process, clay is mixed with a small amount of water and formed in steel molds by applying a pressure of 500 to 15,000 psi. The brick manufacturing process is shown in Figure 8.3-1.

Before firing, the wet clay units that have been formed are almost completely dried in driers that are usually heated by waste heat from the kilns. Many types of kilns are used for firing brick; however, the most common are the tunnel kiln and the periodic kiln. The downdraft periodic kiln is a permanent brick structure that has a number of firebricks where fuel is fired into the furnace. The hot gases from the fuel are drawn up over the bricks, down through them by underground flues, and out of the oven to the chimney. Although fuel efficiency is not as high as that of a tunnel kiln because of lower heat recovery, the uniform temperature distribution through the kiln leads to a good quality product. In most tunnel kilns, cars carrying about 1,250 bricks each travel on rails through the kiln at the rate of one 6-foot car per hour. The fire zone is located near the middle of the kiln and remains stationary.

In all kilns, firing takes place in six steps: evaporation of free water, dehydration, oxidation, vitrification, flashing, and cooling. Normally, gas or residual oil is used for heating, but coal may be used. Total heating time varies with the type of product; for example, 9-inch refractory bricks usually require 50 to 100 hours of firing. Maximum temperatures of about 2000 F (1090 C) are used in firing common brick.

8.3.2 Emissions and Controls[1-3]

Particulate matter is the primary emission in the manufacture of bricks. The main source of dust is the materials handling procedure, which includes drying, grinding, screening, and storing the raw material. Combustion products are emitted from the fuel consumed in the curing, drying, and firing portion of the process. Fluorides, largely in gaseous form, are also emitted from brick manufacturing operations. Sulfur dioxide may be emitted from the bricks when temperatures reach 2500 F (1370 C) or greater; however, no data on such emissions are available.[4]

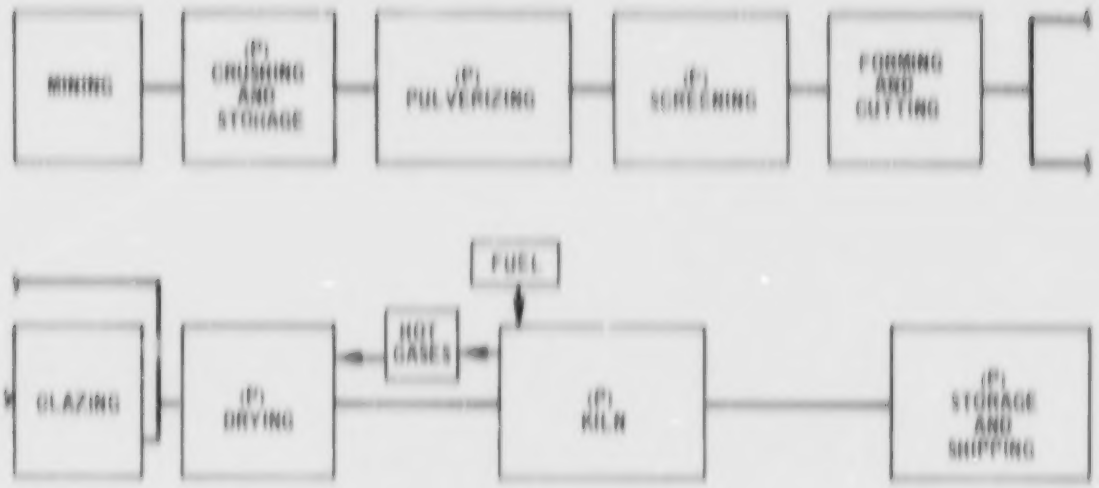

Figure 8.3-1. Basic flow diagram of brick manufacturing process. "P" denotes a major source of particulate emissions.

A variety of control systems may be used to reduce both particulate and gaseous emissions. Almost any type of particulate control system will reduce emissions from the material handling process, but good plant design and housekeeping are also required to keep emissions to a minimum.

The emissions of fluorides can be reduced by operating the kiln at temperatures below 2000°F (1090°C) and by choosing clays with low fluoride content. Satisfactory control can be achieved by scrubbing kiln gases with water; wet cyclonic scrubbers are available that can remove fluorides with an efficiency of 95 percent, or higher.

Emission factors for brick manufacturing are presented in Table 8.3-1. Insufficient data are available to present particle size information.

Table 8.3-1. EMISSION FACTORS FOR BRICK MANUFACTURING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of process	Particulates		Sulfur oxides (SO_x)		Carbon monoxide (CO)		Hydrocarbons (HC)		Nitrogen oxides (NO_x)		Fluorides[b] (HF)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw material handling[c]												
Dryers, grinders, etc.	96	48	--	--	--	--	--	--	--	--	--	--
Storage	3#	1.7	--	--	--	--	--	--	--	--	--	--
Curing and firing[d]												
Tunnel kilns												
Gas-fired	0.04	0.02	Negl	Negl	0.04	0.02	0.02	0.01	0.15	0.08	1.0	0.5
Oil-Fired	0.6	0.2	4.0S[e]	2.0S	Negl	Negl	0.1	0.05	1.1	0.55	1.0	0.5
Coal-Fired	1.0A	0.5A[f]	1.2S	0.6S	1.3	0.65	0.6	0.3	0.9	0.45	1.0	0.5
Periodic kilns												
Gas-fired	0.11	0.05	Negl	Negl	0.11	0.05	0.04	0.02	0.42	0.21	1.0	0.5
Oil-fired	0.9	0.45	5.9S	2.95S	Negl	Negl	0.1	0.05	1.7	0.85	1.0	0.5
Coal-fired	1.6A	0.8A	12.0S	6.0S	2.2	1.1	0.9	0.45	1.4	0.70	1.0	0.5

[a]One brick weighs about 6.5 pounds (2.95 kg). Emission factors expressed as units per unit weight of brick produced.

[b]Based on data from References 3 and 6 through 10.

[c]Based on data from sections on ceramic clay and cement manufacturing in this publication. Because of process variation, some steps may be omitted. Storage losses apply only to that quantity of material stored.

[d]Based on data from References 1 and 5 and emission factors for fuel combustion.

[e]Not volatile.

[f]S = the percent sulfur in the fuel.

[g]A = the percent ash in the coal.

References for Section 8.1

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2. Technical Notes on Brick and Tile Construction. Structural Clay Products Institute, Washington, D.C. Pamphlet Number 9. September 1961.

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8.4 CALCIUM CARBIDE MANUFACTURING

8.4.1 Process Description[1-2]

Calcium carbide is manufactured by heating a mixture of quicklime (CaO) and carbon in an electric-arc furnace, where the lime is reduced by the coke to calcium carbide and carbon monoxide. Metallurgical coke, petroleum coke, or anthracite coal is used as the source of carbon. About 1980 pounds (860 kg) of lime and 1360 pounds (680 kg) of coke yield 1 ton (1 MT) of calcium carbide. There are two basic types of carbide furnaces: (1) the open furnace, in which the carbon monoxide burns to carbon dioxide when it comes in contact with air above the charge; and (2) the closed furnace, in which the gas is collected from the furnace. The molten calcium carbide from the furnace is poured into chill cars or bucket conveyors and allowed to solidify. The finished calcium carbide is dumped into a jaw crusher and then into a cone crusher to form a product of the desired size.

8.4.2 Emissions and Controls

Particulates, acetylene, sulfur compounds, and some carbon monoxide are emitted from the calcium carbide plants. Table 8.4-1 contains emission factors based on one plant in which some particulate matter escapes from the hoods over each furnace and the remainder passes through wet-impingement-type scrubbers before being vented to the atmosphere through a stack. The coke dryers and the furnace-room vents are also sources of emissions.

TABLE 8.4-1. EMISSION FACTORS FOR CALCIUM CARBIDE PLANTS[a]
EMISSION FACTOR RATING: C

Type of source	Particulates		Sulfur oxides		Acetylene	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Electric furnace						
Hoods	18	9	–	–	–	–
Main stack	20	10	3	1.5	–	–
Coke dryer	2	1	3	1.5	–	–
Furnace room vents	26	13	–	–	18	9

[a]Reference 3. Emission factors expressed as units per unit weight of calcium carbide produced.

References for Section 8.4

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8.5 CASTABLE REFRACTORIES

8.5.1 Process Description[1-3]

Castable or fused-cast refractories are manufactured by carefully blending such components as alumina, zirconia, silica, chrome, and magnesia; melting the mixture in an electric-arc furnace at temperatures of 3300F to 4500F (1760 to 3480C); pouring it into molds; and slowly cooling it to the solid state. Fused refractories are less porous and more dense than kiln-fired refractories.

8.5.2 Emissions and Controls[1]

Particulate emissions occur during the drying, crushing, handling, and blending of the components; during the actual melting process; and in the molding phase. Fluorides, largely in the gaseous form, may also be emitted during the melting operations.

The general types of particulate controls may be used on the materials handling aspects of refractory manufacturing. Emissions from the electric-arc furnace, however, are largely condensed fumes and consist of very fine particles. Fluoride emissions can be effectively controlled with a scrubber. Emission factors for castable refractories manufacturing are presented in Table 8.5-1.

Table 8.5-1. PARTICULATE EMISSION FACTORS FOR CASTABLE REFRACTORIES MANUFACTURING[a]
EMISSION FACTOR RATING: E

Type of process	Type of control	Uncontrolled		Controlled	
		lb/ton	kg/MT	lb/ton	kg/MT
Raw material dryer[b]	Baghouse	30	15	0.3	0.15
Raw material crushing and processing[c]	Scrubber			7	3.5
	Cyclone	120	60	45	22.5
Electric arc melting[d]	Baghouse	50	25	0.8	0.4
	Scrubber			10	5
Curing oven[e]	-	0.2	0.1	-	-
Molding and shakeout[b]	Baghouse	25	12.5	0.3	0.15

[a] Fluoride emissions from the melt average about 1.3 pounds of HF per ton of melt (0.65 kg HF/MT melt). Emission factors expressed as units per unit weight of feed material.
[b] Reference 4.
[c] References 4 and 5.
[d] References 4 through 6.
[e] Reference 5.

References for Section 8.8

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5. Unpublished stack test data on refractories. Resources Research, Incorporated. Reston, Virginia. 1969.

6. Unpublished stack test data on refractories. Resources Research, Incorporated. Reston, Virginia. 1967.

8.6 PORTLAND CEMENT MANUFACTURING

Revised by Dennis H. Ackerson

8.6.1 Process Description[1-3]

Portland cement manufacture accounts for about 98 percent of the cement production in the United States. The more than 30 raw materials used to make cement may be divided into four basic components: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). Approximately 3,000 pounds of dry raw materials are required to produce 1 ton of cement. Approximately 35 percent of the raw material weight is removed as carbon dioxide and water vapor. As shown in Figure 8.6-1, the raw materials undergo separate crushing after the quarrying operation, and, when needed for processing, are proportioned, ground, and blended using either the wet or dry process.

In the dry process, the moisture content of the raw material is reduced to less than 1 percent either before or during the grinding operation. The dried materials are then pulverized into a powder and fed directly into a rotary kiln. Usually, the kiln is a long, horizontal, steel cylinder with a refractory brick lining. The kilns are slightly inclined and rotate about the longitudinal axis. The pulverized raw materials are fed into the upper end and travel slowly to the lower end. The kilns are fired from the lower end so that the hot gases pass upward and through the raw material. Drying, decarbonating, and calcining are accomplished as the material travels through the heated kiln, finally burning to incipient fusion and forming the clinker. The clinker is cooled, mixed with about 5 percent gypsum by weight, and ground to the final product fineness. The cement is then stored for later packaging and shipment.

With the wet process, a slurry is made by adding water to the initial grinding operation. Proportioning may take place before or after the grinding step. After the materials are mixed, the excess water is removed and final adjustments are made to obtain a desired composition. This final homogeneous mixture is fed to the kilns as a slurry of 30 to 40 percent moisture or as a wet filtrate of about 20 percent moisture. The burning, cooling, addition of gypsum, and storage are carried out as in the dry process.

8.6.2 Emissions and Controls[1-3,4]

Particulate matter is the primary emission in the manufacture of portland cement. Emissions also include the normal combustion products of the fuel used to supply heat for the kiln and drying operations, including oxides of nitrogen and small amounts of oxides of sulfur.

Sources of dust at cement plants include: (1) quarrying and crushing, (2) raw material storage, (3) grinding and blending (dry process only), (4) clinker production, (5) finish grinding, and (6) packaging. The largest source of emissions within cement plants is the kiln operation, which may be considered to have three units: the feed system, the fuel-firing system, and the clinker-cooling and handling system. The most desirable method of disposing of the collected dust is injection into the burning zone of the kiln and production of clinkers from the dust. If the alkali content of the raw materials is too high, however, some of the dust is discarded or leached before returning to the kiln. In many instances, the maximum allowable alkali content of 0.6 percent (calculated as sodium oxide) restricts the amount of dust that can be recycled. Additional sources of dust emissions are raw material storage piles, conveyors, storage silos, and loading/unloading facilities.

The complications of kiln burning and the large volumes of materials handled have led to the adoption of many control systems for dust collection. Depending upon the emission, the temperature of the effluents in the

Figure 8.6-1. Basic flow diagram of portland cement manufacturing process.

plant in question, and the particulate emission standards in the community, the cement industry generally uses mechanical collectors, electrical precipitators, fabric filter (baghouse) collectors, or combinations of these devices to control emissions.

Table 8.6-1 summarizes emission factors for cement manufacturing and also includes typical control efficiencies of particulate emissions. Table 8.6-2 indicates the particle size distribution for particulate emissions from kilns and cement plants before control systems are applied.

Table 8.6-1. EMISSION FACTORS FOR CEMENT MANUFACTURING WITHOUT CONTROLS[a,b,c]
EMISSION FACTOR RATING: B

Pollutant	Dry Process		Wet process	
	Kilns	Dryers, grinders, etc.	Kilns	Dryers, grinders, etc.
Particulate[d]				
lb/ton	245.0	90.0	220.0	32.0
kg/MT	122.0	48.0	114.0	16.0
Sulfur dioxide[e]				
Mineral source[f]				
lb/ton	10.2	"	10.2	"
kg/MT	5.1	"	5.1	"
Gas combustion				
lb/ton	Neg[g]	"	Neg	"
kg/MT	Neg	"	Neg	"
Oil combustion				
lb/ton	4.25[h]	"	4.25	"
kg/MT	2.15	"	2.15	"
Coal combustion				
lb/ton	6.85	"	6.85	"
kg/MT	3.45	"	3.45	"
Nitrogen oxides				
lb/ton	2.6	"	2.6	"
kg/MT	1.3	"	1.3	"

[a] One barrel of cement weighs 376 pounds (171 kg).

[b] These emission factors include emissions from fuel combustion, which should not be calculated separately.

[c] References 1 and 2.

[d] Typical collection efficiencies for kilns, dryers, grinders, etc., are: multicyclones, 80 percent; electrostatic precipitators, 95 percent; electrostatic precipitators with multicyclones, 97.5 percent; and fabric filter units, 99.8 percent.

[e] The sulfur dioxide factors presented take into account the reactions with the alkaline dusts when no baghouses are used. With baghouses, approximately 50 percent more SO_2 is removed because of reactions with the alkaline particulate filter cake. Also note that the total SO_2 from the kiln is determined by summing emission contributions from the mineral source and the appropriate fuel.

[f] These emissions are the result of sulfur being present in the raw materials and are thus dependent upon source of the raw materials used. The 10.2 lb/ton (5.1 kg/MT) factor accounts for part of the available sulfur remaining behind in the product because of its alkaline nature and affinity for SO_2.

[g] Negligible.

[h] S is the percent sulfur in fuel.

Table 8.6.2. SIZE DISTRIBUTION OF DUST EMITTED FROM KILN OPERATIONS WITHOUT CONTROLS[1,5]

Particle size, μm	Kiln dust finer than corresponding particle size, %
60	93
50	90
40	84
30	74
20	58
10	38
5	23
1	3

Sulfur dioxide may be generated from the sulfur compounds in the ores as well as from combustion of fuel. The sulfur content of both ores and fuels will vary from plant to plant and with geographic location. The alkaline nature of the cement, however, provides for direct absorption of SO_2 into the product. The overall control inherent in the process is approximately 75 percent or greater of the available sulfur in ore and fuel if a baghouse that allows the SO_2 to come in contact with the cement dust is used. Control, of course, will vary according to the alkali and sulfur content of the raw materials and fuel.[5]

References for Section 8.6

1. Kreichelt, T. E., D. A. Kennedy, and S. T. Cuffe. Atmospheric Emissions from the Manufacture of Portland Cement. U. S. DHEW, Public Health Service. Cincinnati, Ohio. PHS Publication Number 999-AP-17, 1967.

2. Unpublished standards of performance for new and substantially modified portland cement plants. Environmental Protection Agency, Bureau of Stationary Source Pollution Control, Research Triangle Park, N.C. August 1971.

3. A Study of the Cement Industry in the State of Missouri. Resources Research Inc., Reston, Va. Prepared for the Air Conservation Commission of the State of Missouri. December 1967.

4. Standards of Performance for New Stationary Sources. Environmental Protection Agency. Federal Register, 36(247, Pt II). December 23, 1971.

5. Particulate Pollutant System Study. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Air Pollution Control Office, Research Triangle Park, N.C., under Contract Number CPA 22-69-104. May 1971.

6. Restriction of Emissions from Portland Cement Works. VDI Richtlinien. Duesseldorf, Germany. February 1967.

8.7 CERAMIC CLAY MANUFACTURING

8.7.1 Process Description[1]

The manufacture of ceramic clay involves the conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding, and blending of the desired ore varieties. The basic raw materials in ceramic clay manufacture are kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and montmorillonite [$(Mg, Ca)\ O \cdot Al_2O_3 \cdot 5SiO_2 \cdot nH_2O$] clays. These clays are refined by separation and bleaching, blended, kiln-dried, and formed into such items as whiteware, heavy clay products (brick, etc.), various stoneware, and other products such as diatomaceous earth, which is used as a filter aid.

8.7.2 Emissions and Controls[1]

Emissions consist primarily of particulates, but some fluorides and acid gases are also emitted in the drying process. The high temperatures of the firing kilns are also conducive to the fixation of atmospheric nitrogen and the subsequent release of NO, but no published information has been found for gaseous emissions. Particulates are also emitted from the grinding process and from storage of the ground product.

Factors affecting emissions include the amount of material processed, the type of grinding (wet or dry), the temperature of the drying kilns, the gas velocities and flow direction in the kilns, and the amount of fluorine in the ores.

Common control techniques include settling chambers, cyclones, wet scrubbers, electrostatic precipitators, and bag filters. The most effective control is provided by cyclones for the coarser material, followed by wet scrubbers, bag filters, or electrostatic precipitators for dry dust. Emission factors for ceramic clay manufacturing are presented in Table 8.7-1.

Table 8.7-1. PARTICULATE EMISSION FACTORS FOR CERAMIC CLAY MANUFACTURING[a]
EMISSION FACTOR RATING: A

Type of process	Uncontrolled		Cyclone[b]		Multiple-unit cyclone and scrubber[c]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Drying[d]	70	35	18	9	7	3.5
Grinding[d]	76	38	19	9.5	-	-
Storage[e]	34	17	8	4	-	-

[a]Emission factors expressed as units per unit weight of input to process.
[b]Approximate collection efficiency: 75 percent.
[c]Approximate collection efficiency: 90 percent.
[d]References 2 through 5.
[e]Reference 2.

References for Section 8.7-1

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Allen, G. L., et al. Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County. Department of Interior, Bureau of Mines. Washington, D.C. Information Circular Number 7627. April 1953.

3. Private Communication between Resources Research, Incorporated, Reston, Virginia, and the State of New Jersey Air Pollution Control Program, Trenton, New Jersey. July 30, 1969.

4. Henn, J. L., et al. Methods for Producing Alumina from Clay: An Evaluation of Two Lime Sinter Processes. Department of Interior, Bureau of Mines. Washington, D.C. Report of Investigations Number 7209. September 1969.

5. Peters, F. A., et al. Methods for Producing Alumina from Clay: An Evaluation of the Lime-Soda Sinter Process. Department of Interior, Bureau of Mines. Washington, D.C. Report of Investigation Number 6927. 1967.

8.8 CLAY AND FLY-ASH SINTERING

8.8.1 Process Description[1]

Although the processes for sintering fly ash and clay are similar, there are some distinctions that justify a separate discussion of each process. Fly-ash sintering plants are generally located near the source, with the fly ash delivered to a storage silo at the plant. The dry fly ash is moistened with a water solution of lignin and agglomerated into pellets or balls. This material goes to a traveling-grate sintering machine where direct contact with hot combustion gases sinters the individual particles of the pellet and completely burns off the residual carbon in the fly ash. The product is then crushed, screened, graded, and stored in yard piles.

Clay sintering involves the driving off of entrained volatile matter. It is desirable that the clay contain a sufficient amount of volatile matter so that the resultant aggregate will not be too heavy. It is thus sometimes necessary to mix the clay with "finely pulverized coke (up to 12 percent coke by weight)".[2] In the sintering process the clay is first mixed with pulverized coke, if necessary, and then pelletized. The clay is next sintered in a rotating kiln or on a traveling grate. The sintered pellets are then crushed, screened, and stored, in a procedure similar to that for fly ash pellets.

8.8.2 Emissions and Controls[1]

In fly ash sintering, improper handling of the fly ash creates a dust problem. Adequate design features, including fly-ash wetting systems and particulate collection systems on all transfer points and on crushing and screening operations, would greatly reduce emissions. Normally, fabric filters are used to control emissions from the storage silo, and emissions are low. The absence of this dust collection system, however, would create a major emission problem. Moisture is added at the point of discharge from the silo to the agglomerator, and very few emissions occur there. Normally, there are few emissions from the sintering machine, but if the grate is not properly maintained, a dust problem is created. The consequent crushing, screening, handling, and storage of the sintered product also create dust problems.

In clay sintering, the addition of pulverized coke presents an emission problem because the sintering of coke-impregnated dry pellets produces more particulate emissions than the sintering of natural clay. The crushing, screening, handling, and storage of the sintered clay pellets creates dust problems similar to those encountered in fly ash sintering. Emission factors for both clay and fly ash sintering are shown in Table 8.8-1.

Table 8.8-1. PARTICULATE EMISSION FACTORS FOR SINTERING OPERATIONS[a]
EMISSION FACTOR RATING: C

Type of material	Sintering operation[b]		Crushing, screening, and yard storage[b,c]	
	lb/ton	kg/MT	lb/ton	kg/MT
Fly ash[d]	110	55	e	e
Clay mixed with coke[f,g]	40	20	15	7.5
Natural clay[h,i]	12	6	12	6

[a]Emission factors expressed as units per unit weight of finished product.
[b]Cyclones would reduce this emission by about 80 percent.
Scrubbers would reduce this emission by about 90 percent.
[c]Based on data in section on stone quarrying and processing.
[d]Reference 1.
[e]Included in sintering losses.
[f]90 percent clay, 10 percent pulverized coke; traveling grate, single pass, up draft sintering machine.
[g]References 3 through 5.
[h]Rotary dryer sinterer.
[i]Reference 2.

References for Section 8.8

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA 22-69-119. April 1970.

2. Communication between Resources Research, Incorporated, Reston, Virginia, and a clay sintering firm. October 2, 1969.

3. Communication between Resources Research, Incorporated, Reston, Virginia, and an anonymous Air Pollution Control Agency. October 16, 1969.

4. Henn, J. J. et al. Methods for Producing Alumina from Clay: An Evaluation of Two Lime Sinter Processes. Department of the Interior, Bureau of Mines. Washington, D.C. Report of Investigation Number 7209. September 1969.

5. Peters, E. A. et al. Methods for Producing Alumina from Clay: An Evaluation of the Lime-Soda Sinter Process. Department of the Interior, Bureau of Mines. Washington, D.C. Report of Investigation Number 6927. 1967.

8.9 COAL CLEANING

8.9.1 Process Description[1]

Coal cleaning is the process by which undesirable materials are removed from bituminous and anthracite coal and lignite. The coal is screened, classified, washed, and dried at coal preparation plants. The major sources of air pollution from these plants are the thermal dryers. Seven types of thermal dryers are presently used: rotary, screen, cascade, continuous carrier, flash or suspension, multilouver, and fluidized bed. The three major types, however, are the flash, multilouver, and fluidized bed.

In the flash dryer, coal is fed into a stream of hot gases where instantaneous drying occurs. The dried coal and wet gases are drawn up a drying column and into the cyclone for separation. In the multilouver dryer, hot gases are passed through falling curtains of coal. The coal is raised by flights of a specially designed conveyor. In the fluidized bed the coal is suspended and dried above a perforated plate by rising hot gases.

8.9.2 Emissions and Controls[1]

Particulates in the form of coal dust constitute the major air pollution problem from coal cleaning plants. The crushing, screening, or sizing of coal are minor sources of dust emissions; the major sources are the thermal dryers. The range of concentration, quantity, and particle size of emissions depends upon the type of collection equipment used to reduce particulate emissions from the dryer stack. Emission factors for coal-cleaning plants are shown in Table 8.9-1. Footnote b of the table lists various types of control equipment and their possible efficiencies.

Table 8.9-1. PARTICULATE EMISSION FACTORS FOR THERMAL COAL DRYERS[a]
EMISSION FACTOR RATING: B

Type of dryer	Uncontrolled emissions[b]	
	lb/ton	kg/MT
Fluidized bed[c]	20	10
Flash[c]	16	8
Multilouver[d]	25	12.5

[a] Emission factors expressed as units per unit weight of coal dried.
[b] Typical collection efficiencies are: cyclone collectors (product recovery), 70 percent; multiple cyclones (product recovery), 85 percent; water sprays following cyclones, 85 percent; and wet scrubber following cyclones, 98 to 99.8 percent.
[c] References 2 and 3.
[d] Reference 4.

References for Section 8.9

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc., Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA 22-69-119. April 1970.

2. Unpublished stack test results on thermal coal dryers. Pennsylvania Department of Health, Bureau of Air Pollution Control, Harrisburg, Pa.

3. Amherst's Answer to Air Pollution Laws. Coal Mining and Processing. p. 36-39. February 1970.

4. Jones, D. W. Dust Collection at Moss. No. 3. Mining Congress Journal. 53(7):53-56. July 1967.

8.10 CONCRETE BATCHING

8.10.1 Process Description[1-3]

Concrete batching involves the proportioning of sand, gravel, and cement by means of weigh hoppers and conveyors into a mixing receiver such as a transit mix truck. The required amount of water is also discharged into the receiver along with the dry materials. In some cases, the concrete is prepared for on-site building construction work or for the manufacture of concrete products such as pipes and prefabricated construction parts.

8.10.2 Emissions and Controls[1]

Particulate emissions consist primarily of cement dust, but some sand and aggregate gravel dust emissions do occur during batching operations. There is also a potential for dust emissions during the unloading and conveying of concrete and aggregates at these plants and during the loading of dry-batched concrete mix. Another source of dust emissions is the traffic of heavy equipment over unpaved or dusty surfaces in and around the concrete batching plant.

Control techniques include the enclosure of dumping and loading areas, the enclosure of conveyors and elevators, filters on storage bin vents, and the use of water sprays. Table 8.10-1 presents emission factors for concrete batch plants.

Table 8.10-1. PARTICULATE EMISSION FACTORS FOR CONCRETE BATCHING[a]
EMISSION FACTOR RATING: C

Concrete batching[b]	Emission	
	lb/yd^3 of concrete	kg/m^3 of concrete
Uncontrolled	0.2	0.12
Good control	0.02	0.012

[a]One cubic yard of concrete weighs 4,050 pounds (1 m^3 = 2400 kg). The cement content varies with the type of concrete mixed, but 740 pounds of cement per yard (438 kg/m^3) may be used as a typical value.

[b]Reference 4.

References for Section 8.10

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA 22-69-119. April 1970.

2. Vincent, E. J. and J. L. McGinnity. Concrete Batching Plants. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 334-335.

3. Communication between Resources Research, Incorporated, Reston, Virginia, and the National Ready Mix Concrete Association. September 1969.

4. Allen, G. L. et al. Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County. Department of the Interior, Bureau of Mines. Washington, D.C. Information Circular Number 7637. April 1953.

8.11 FIBER GLASS MANUFACTURING

Revised by James H. Southerland

8.11.1 Process Description

Glass fiber products are manufactured by melting various raw materials to form glass (predominantly borosilicate), drawing the molten glass into fibers, and coating the fibers with an organic material. The two basic types of fiber glass products, textile and wool, are manufactured by different processes. Typical flow diagrams are shown in Figures 8.11-1 and 8.11-2.

8.11.1.1 Textile Products. In the manufacture of textiles, the glass is normally produced in the form of marbles after refining at about 2800°F (1540°C) in a regenerative, recuperative, or electric furnace. The marble forming stage can be omitted with the molten glass passing directly to orifices to be formed or drawn into fiber filaments. The fiber filaments are collected on spools as continuous fibers and staple yarns, or in the form of a fiber glass mat on a flat, moving surface. An integral part of the textile process is treatment with organic binder materials followed by a curing step.

8.11.1.2 Wool Products. In the manufacture of wool products, which are generally used in the construction industry as insulation, ceiling panels, etc., the molten glass is most frequently fed directly into the forming line without going through a marble stage. Fiber formation is accomplished by air blowing, steam blowing, flame blowing, or centrifuge forming. The organic binder is sprayed onto the hot fibers as they fall from the forming device. The fibers are collected on a moving, flat surface and transported through a curing oven at a temperature of 400° to 600°F (200° to 315°C) where the binder sets. Depending upon the product, the wool may also be compressed as a part of this operation.

8.11.2 Emissions and Controls[1]

The major emissions from the fiber glass manufacturing processes are particulates from the glass-melting furnace, the forming line, the curing oven, and the product cooling line. In addition, gaseous organic emissions occur from the forming line and curing oven. Particulate emissions from the glass-melting furnace are affected by basic furnace design, type of fuel (oil, gas, or electricity), raw material size and composition, and type and volume of the furnace heat-recovery system. Organic and particulate emissions from the forming line are most affected by the composition and quality of the binder and by the spraying techniques used to coat the fibers; very fine spray and volatile binders increase emissions. Emissions from the curing ovens are affected by oven temperature and binder composition, but direct-fired afterburners with heat exchangers may be used to control these emissions. Emission factors for fiber glass manufacturing are summarized in Table 8.11-1.

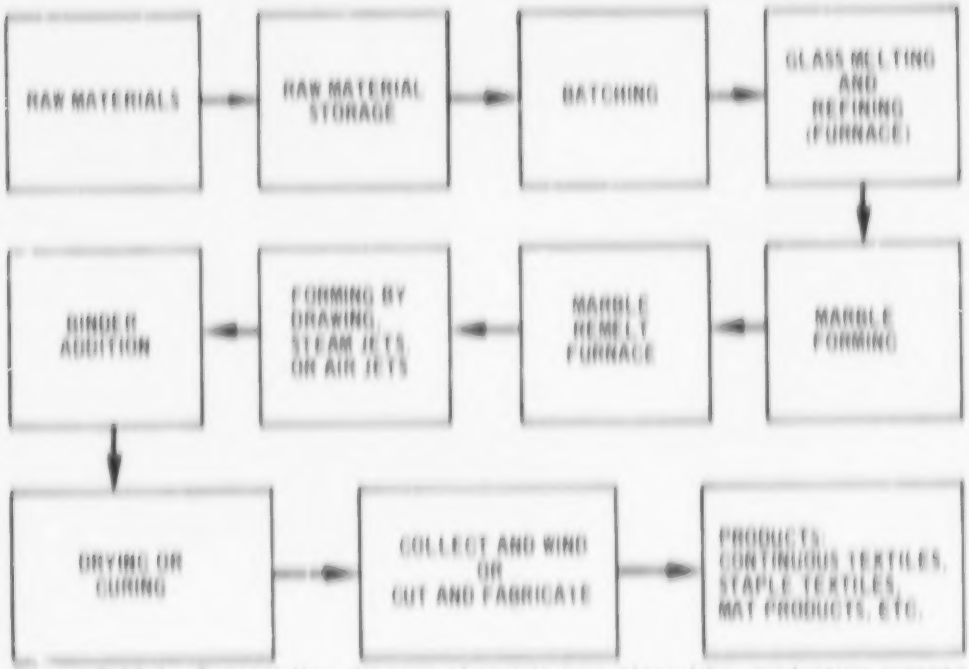
RAW MATERIALS
RAW MATERIAL STORAGE
BATCHING
GLASS MELTING AND REFINING (FURNACE)
MARBLE FORMING
MARBLE REMELT FURNACE
FORMING BY DRAWING, STEAM JETS, OR AIR JETS
BINDER ADDITION
DRYING OR CURING
COLLECT AND WIND OR CUT AND FABRICATE
PRODUCTS: CONTINUOUS TEXTILES, STAPLE TEXTILES, MAT PRODUCTS, ETC.

Figure 8.11-1. Typical flow diagram of textile-type glass fiber production process.

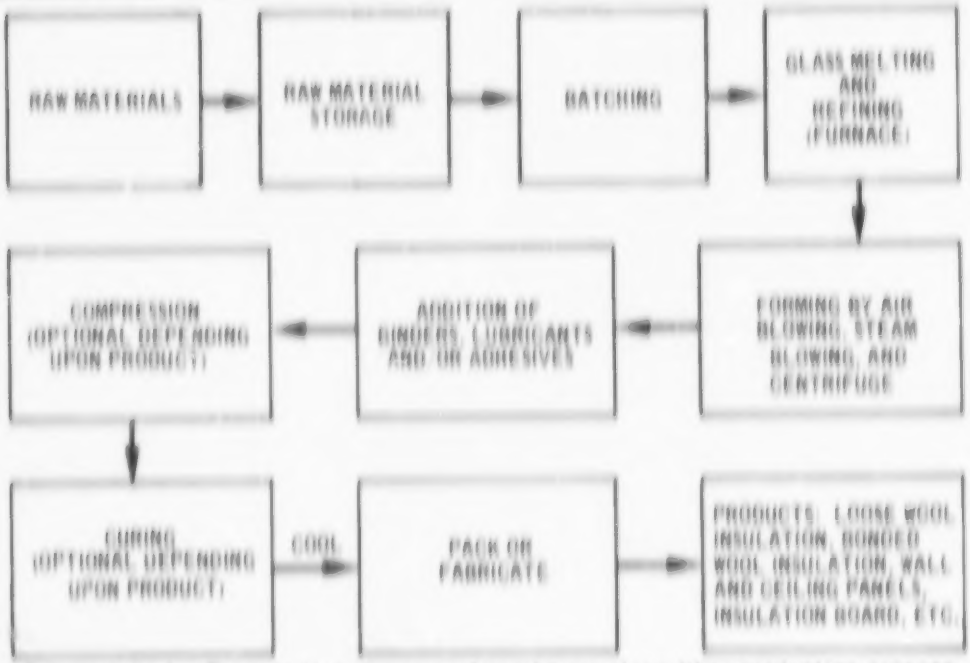
RAW MATERIALS
RAW MATERIAL STORAGE
BATCHING
GLASS MELTING AND REFINING (FURNACE)
FORMING BY AIR BLOWING, STEAM BLOWING, AND CENTRIFUGE
ADDITION OF BINDERS, LUBRICANTS AND/OR ADHESIVES
COMPRESSION (OPTIONAL DEPENDING UPON PRODUCT)
CURING (OPTIONAL DEPENDING UPON PRODUCT)
COOL
PACK OR FABRICATE
PRODUCTS: LOOSE WOOL INSULATION, BONDED WOOL INSULATION, WALL AND CEILING PANELS, INSULATION BOARD, ETC.

Figure 8.11-2. Typical flow diagram of wool-type glass fiber production process.

Table 8.17.1. EMISSION FACTORS FOR FIBER GLASS MANUFACTURING WITHOUT CONTROLS[a,b]
EMISSION FACTOR RATING: A

Type of process	Particulate		Sulfur oxides (SO_x)		Carbon monoxide		Nitrogen oxides (NO_x)		Fluorides	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Textile products										
Glass furnace[c]										
Regenerative	16.4	8.2	28.6	14.3	1.1	0.6	9.2	4.6	3.8	1.9
Recuperative	27.8	13.7	2.7	1.4	0.9	0.5	29.2	14.6	17.5	8.3
Electric	ND[d]	–	–	–	–	–	–	–	–	–
Forming	1.6	0.8	–	–	–	–	–	–	–	–
Curing oven	1.2	0.6	–	–	1.5	0.8	2.6	1.3	–	–
Wool products[e]										
Glass furnace[c]										
Regenerative	27.5	10.8	10.0	5.0	0.25	0.13	5.0	2.5	0.12	0.06
Recuperative	28.3	14.2	9.5	4.8	0.25	0.13	1.78	0.9	0.11	0.06
Electric	0.6	0.3	0.04	0.02	0.05	0.03	0.27	0.14	0.02	0.01
Forming	57.6	28.8	–	–	–	–	–	–	–	–
Curing oven	3.5	1.8	ND	–	1.7	0.9	1.1	0.6	–	–
Cooling	1.3	0.7	–	–	0.2	0.1	0.2	0.1	–	–

[a] Emission factors expressed as unit mass per unit weight of material processed.

[b] Reference 1.

[c] Does not include cullremelt used at any one plant.

[d] No data available.

[e] In addition, 0.08 lb/ton (0.05 kg/MT) ammonia and 0.2 lb/ton (0.1 kg/MT) phenols are released from the wool curing and cooling operations.

References for Section 8.11

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc., Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Kirk-Othmer. Encyclopedia of Chemical Technology, Vol. 8. 2nd Ed. New York, Interscience (John Wiley and Sons, Inc.). 1966. p. 564-566.

3. Private correspondence from S. H. Thomas, Owens-Corning Fiberglas Corp., Toledo, Ohio including intra-company correspondence from R. J. Powels. Subject: Air Pollutant Emission Factors. April 26, 1973.

8.12 FRIT MANUFACTURING

8.12.1 Process Description[1-2]

Frit is used in enameling iron and steel and in glazing porcelain and pottery. In a typical plant, the raw materials consist of a combination of materials such as borax, feldspar, sodium fluoride or fluorspar, soda ash, zinc oxide, litharge, silica, boric acid, and zircon. Frit is prepared by fusing these various minerals in a smelter, and the molten material is then quenched with air or water. This quenching operation causes the melt to solidify rapidly and shatter into numerous small glass particles, called frit. After a drying process, the frit is finely ground in a ball mill where other materials are added.

8.12.2 Emissions and Controls[2]

Significant dust and fume emissions are created by the frit-smelting operation. These emissions consist primarily of condensed metallic oxide fumes that have volatilized from the molten charge. They also contain mineral dust carryover and sometimes hydrogen fluoride. Emissions can be reduced by not rotating the smelter too rapidly (to prevent excessive dust carry-over) and by not heating the batch too rapidly or too long (to prevent volatilizing the more fusible elements).

The two most feasible control devices for frit smelters are baghouses and venturi water scrubbers. Emission factors for frit smelters are shown in Table 8.12.1. Collection efficiencies obtainable for venturi scrubbers are also shown in the table.

Table 8.12.1. EMISSION FACTORS FOR FRIT SMELTERS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of furnace	Particulates[b]		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Rotary	16	8	5	2.5

[a]Reference 2. Emission factors expressed as units per unit weight of charge.
[b]A venturi scrubber with a 21 inch (0.36 mm) water gauge pressure drop can reduce particulate emissions by 87 percent and fluorides by 98 percent.

References for Section 8.12

1. Dupree, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 37-38.

2. Spinks, J. T. Frit Smelters. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 738-744.

8.13 GLASS MANUFACTURING

8.13.1 Process Description[1-3]

Nearly all glass produced commercially is one of five basic types: soda-lime, lead, fused silica, borosilicate, and 96 percent silica. Of these, the modern soda-lime glass constitutes 90 percent of the total glass produced and will thus be the only type discussed in this section. Soda-lime glass is produced on a massive scale in large, direct-fired, continuous-melting furnaces in which the blended raw materials are melted at 2700°F (1480°C) to form glass.

8.13.2 Emissions and Controls[1-3]

Emissions from the glass-melting operation consist primarily of particulates and fluorides, if fluoride-containing fluxes are used in the process. Because the dust emissions contain particles that are only a few microns in diameter, cyclones and centrifugal scrubbers are not as effective as baghouses or filters in collecting particulate matter. Table 8.13-1 summarizes the emission factors for glass melting.

Table 8.13-1. EMISSION FACTORS FOR GLASS MELTING
EMISSION FACTOR RATING: D

Type of glass	Particulates[a]		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Soda-lime	9	1	4F[c]	2F[c]

[a] Reference 4. Emission factors expressed as units per unit weight of glass produced.
[b] Reference 4.
[c] F equals weight percent of fluoride in input to furnace; e.g., if fluoride content is 5 percent, the emission factor would be 4F or 20 (2F or 10).

References for Section 8.13

1. Netzley, A. B. and J. L. McGinnity. Glass Manufacture. In: Air Pollution Engineering Manual. Danielson, J.A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 729-730.

2. Duprey, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 38.

3. Technical Progress Report: Control of Stationary Sources. Los Angeles County Air Pollution Control District. 7. April 1960.

4. Semrau, K. T. Emissions of Fluorides from Industrial Processes: A Review. J. Air Pol. Control Assn. 7:2:92-108. August 1957.

8.14 GYPSUM MANUFACTURING

8.14.1 Process Description[1]

Gypsum, or hydrated calcium sulfate, is a naturally occurring mineral that is an important building material. When heated gypsum loses its water of hydration. It becomes plaster of paris, or when blended with fillers it serves as wall plaster. In both cases the material hardens as water reacts with it to form the solid crystalline hydrate.[1-2]

The usual method of calcination of gypsum consists of grinding the mineral and placing it in large, externally heated calciners. Complete calcination of 1 ton (0.907 MT) of plaster takes about 3 hours and requires about 1.0 million Btu (0.25 million kcal).[1-2]

8.14.2 Emissions[1]

The process of calcining gypsum appears to be devoid of any air pollutants because it involves simply the relatively low-temperature removal of the water of hydration. However, the gases created by the release of the water of crystallization carry gypsum rock dust and partially calcined gypsum dust into the atmosphere.[6] In addition, dust emissions occur from the grinding of the gypsum before calcining and from the mixing of the calcined gypsum with filler. Table 8.14-1 presents emission factors for gypsum processing.

Table 8.14-1. PARTICULATE EMISSION FACTORS FOR GYPSUM PROCESSING[a]
EMISSION FACTOR RATING: C

Type of process	Uncontrolled emissions		With fabric filter		With cyclone and electrostatic precipitator	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw material dryer (if used)	40	20	0.2	0.1	0.4	0.2
Primary grinder	1	0.5	0.001	0.0005	–	–
Calciner	90	45	0.1	0.05	–	–
Conveying	0.7	0.35	0.001	0.0005	–	–

[a] Reference 1. Emission factors expressed in units per unit weight of process throughput.

References for Section 8.14

1. Air Pollutant Emission Factors. Final Report. Resources Research Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA 22-69-119. April 1970.

2. Shreve, R. N. Chemical Process Industries, 3rd Ed. New York, McGraw-Hill Book Company. 1967. p. 180-182.

3. Havinghorst, R. A Quick Look at Gypsum Manufacture. Chem. Eng. 72:153-54. January 4, 1965.

4. Work, L. T. and A. I. Stern. Size Reduction and Size Enlargement. In: Chemical Engineers Handbook. 4th Ed. New York, McGraw-Hill Book Company. 1963. p. 51.

5. Private communication on emissions from gypsum plants between M. M. Hanbook and the National Gypsum Association. Chicago, Illinois. January 1970.

6. Calhane, F. R. Chem. Eng. Progr. 64:72. January 1, 1968.

7. Communication between Resources Research, Incorporated, Reston, Virginia, and the Maryland State Department of Health, Baltimore, Maryland. November 1969.

8.15 LIME MANUFACTURING

8.15.1 General[1]

Lime (CaO) is the high-temperature product of the calcination of limestone ($CaCO_3$). Lime is manufactured in vertical or rotary kilns fired by coal, oil, or natural gas.

8.15.2 Emissions and Controls[1]

Atmospheric emissions in the lime manufacturing industry include particulate emissions from the mining, handling, crushing, screening, and calcining of the limestone and combustion products from the kilns. The vertical kilns, because of a larger size of charge material, lower air velocities, and less agitation, have considerably lower particulate emissions. Control of emissions from these vertical kilns is accomplished by sealing the exit of the kiln and exhausting the gases through control equipment.

Particulate emission problems are much greater on the rotary kilns because of the smaller size of the charge material, the higher rate of fuel consumption, and the greater air velocities through the rotary chamber. Methods of control on rotary kiln plants include simple and multiple cyclones, wet scrubbers, baghouses, and electrostatic precipitators.[2] Emission factors for lime manufacturing are summarized in Table 8.15.1.

Table 8.15.1. PARTICULATE EMISSION FACTORS FOR LIME MANUFACTURING WITHOUT CONTROLS[a] EMISSION FACTOR RATING: B

Operation	Emissions[b]	
	lb/ton	kg/MT
Crushing[c]		
Primary	31	15.6
Secondary	2	1
Calcining[d]		
Vertical kiln	8	4
Rotary kiln	200	100

[a] Emission factors expressed as pounds per ton weight of lime processed.

[b] Cyclones could reduce these factors by about 70 percent. Venturi scrubbers could reduce these factors by about 96 to 99 percent. Fabric filters could reduce these factors by about 99 percent.

[c] Reference 3.

[d] References 2, 4, and 5.

References for Section 8.15

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Lewis, C. and B. Crocker. The Lime Industry's Problem of Airborne Dust. J. Air Pol. Control Assoc. 19:31-39, January 1969.

3. State of Maryland Emission Inventory Data. Maryland State Department of Health, Baltimore, Maryland. 1969.

4. A Study of the Lime Industry in the State of Missouri for the Air Conservation Commission of the State of Missouri. Reston, Virginia, Resources Research, Incorporated. December 1967. p. 54.

5. Communication between Midwest Research Institute and a control device manufacturer. 1968.

8.16 MINERAL WOOL MANUFACTURING

8.16.1 Process Description[1-2]

The product mineral wool used to be divided into three categories: slag wool, rock wool, and glass wool. Today, however, straight slag wool and rock wool as such are no longer manufactured. A combination of slag and rock constitutes the charge material that now yields a product classified as a mineral wool, used mainly for thermal and acoustical insulation.

Mineral wool is made primarily in cupola furnaces charged with blast-furnace slag, silica rock, and coke. The charge is heated to a molten state at about 3000°F (1650°C) and then fed to a blow chamber, where steam atomizes the molten rock into globules that develop long fibrous tails as they are drawn to the other end of the chamber. The wool blanket formed is next conveyed to an oven to cure the binding agent and then to a cooler.

8.16.2 Emissions and Controls

The major source of emissions is the cupola or furnace stack. Its discharge consists primarily of condensed fumes that have volatilized from the molten charge and gases such as sulfur oxides and fluorides. Minor sources of particulate emissions include the blowchamber, curing oven, and cooler. Emission factors for various stages of mineral wool processing are shown in Table 8.16.1. The effect of control devices on emissions is shown in footnotes to the table.

Table 8.16-1. EMISSION FACTORS FOR MINERAL WOOL PROCESSING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of process	Particulates		Sulfur oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Cupola	22	11	0.02	0.01
Reverberatory furnace	5	2.5	Neg[b]	Neg
Blow chamber[c]	17	8.5	Neg	Neg
Curing oven[d]	4	?	Neg	Neg
Cooler	2	1	Neg	Neg

[a]Reference 2. Emission factors expressed as units per unit weight of charge.
[b]Negligible.
[c]A centrifugal water scrubber can reduce particulate emissions by 80 percent.
[d]A direct flame afterburner can reduce particulate emissions by 50 percent.

References for Section 8.16

1. Duprey, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 39-40.

2. Spinks, J. L. Mineral Wool Furnaces. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.). U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 343-347.

8.17 PERLITE MANUFACTURING

8.17.1 Process Description[1-2]

Perlite is a glassy volcanic rock consisting of oxides of silicon and aluminum combined as a natural glass by water of hydration. By a process called exfoliation, the material is rapidly heated to release water of hydration and thus to expand the spherules into low-density particles used primarily as aggregate in plaster and concrete. A plant for the expansion of perlite consists of ore unloading and storage facilities, a furnace feeding device, an expanding furnace, provisions for gas and product cooling, and product-classifying and product-collecting equipment. Vertical furnaces, horizontal stationary furnaces, and horizontal rotary furnaces are used for the exfoliation of perlite, although the vertical types are the most numerous. Cyclone separators are used to collect the product.

8.17.2 Emissions and Controls[2]

A fine dust is emitted from the outlet of the last product collector in a perlite expansion plant. The fineness of the dust varies from one plant to another, depending upon the desired product. In order to achieve complete control of these particulate emissions, a baghouse is needed. Simple cyclones and small multiple cyclones are not adequate for collecting the fine dust from perlite furnaces. Table 8.17.1 summarizes the emissions from perlite manufacturing.

Table 8.17.1. PARTICULATE EMISSION FACTORS FOR PERLITE EXPANSION FURNACES WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of furnace	Emissions[b]	
	lb/ton	kg/MT
Vertical	21	10.5

[a] References 3. Emission factors expressed as pound per ... ton weight of charge.

[b] Primary cyclones will collect 80 percent of the particulates above 20 micrometers, and baghouses will collect 98 percent of the particles above 20 micrometers.[1]

References for Section 8.17

1. Duprey, R. L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 39.

2. Vincent, L. J. Perlite Expanding Furnaces. In: Air Pollution Engineering Manual. Danielson, J. A. (ed.) U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. PHS Publication Number 999-AP-40. 1967. p. 350-353.

3. Unpublished data on perlite expansion furnace. National Center for Air Pollution Control. Cincinnati, Ohio. July 1967.

8.18 PHOSPHATE ROCK PROCESSING

8.18.1 Process Description[1]

Phosphate rock preparation involves beneficiation to remove impurities, drying to remove moisture, and grinding to improve reactivity. Usually, direct-fired rotary kilns are used to dry phosphate rock. These dryers burn natural gas or fuel oil and are fired countercurrently. The material from the dryers may be ground before storage in large storage silos. Air-swept ball mills are preferred for grinding phosphate rock.

8.18.2 Emissions and Controls[1]

Although there are no significant emissions from phosphate rock beneficiation plants, emissions in the form of fine rock dust may be expected from drying and grinding operations. Phosphate rock dryers are usually equipped with dry cyclones followed by wet scrubbers. Particulate emissions are usually higher when drying pebble rock than when drying concentrate because of the small adherent particles of clay and shale on the rock. Phosphate rock grinders can be a considerable source of particulates. Because of the extremely fine particle size, baghouse collectors are normally used to reduce emissions. Emission factors for phosphate rock processing are presented in Table 8.18.1.

Table 8.18.1. PARTICULATE EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of source	Emissions	
	lb/ton	kg/MT
Drying[b,c]	15	7.5
Grinding[b,d]	20	10
Transfer and storage[b,e]	2	1
Open storage piles[f]	40	20

[a]Emission factors expressed as units per unit mass of phosphate rock.

[b]References 2 and 3.

[c]Dry cyclones followed by wet scrubbers can reduce emissions by 86 to 99 percent.

[d]Dry cyclones followed by fabric filters can reduce emissions by 99.8 to 99.9 percent.

[e]Reference 3.

References for Section 8.18

1. Stern, A. (ed.). In: Air Pollution, Vol. III, 2nd Ed. Sources of Air Pollution and Their Control. New York, Academic Press. 1968. p. 221-222.

2. Unpublished data from phosphate rock preparation plants in Florida. Midwest Research Institute. June 1970.

3. Control Techniques for Fluoride Emissions. Internal document. U.S. Environmental Protection Agency, Office of Air Programs, Durham, N.C. p. 4-36, 4-36, and 4-34.

8.19 SAND AND GRAVEL PROCESSING

By: James H. Southerland

8.19.1 Process Description[1]

Deposits of sand and gravel, the consolidated granular materials resulting from the natural disintegration of rock or stone, are found in banks and pits and in subterranean and subaqueous beds.

Depending upon the location of the deposit, the materials are excavated using power shovels, draglines, cableways, suction dredge pumps, or other apparatus; light charge blasting may be necessary to loosen the deposit. The materials are transported to the processing plant by suction pump, earth mover, barge, truck, or other means. The processing of sand and gravel for a specific market includes the use of different combinations of washers, screens and classifiers, which segregate particle sizes; crushers, which reduce oversize material; and storage and loading facilities.

8.19.2 Emissions[2-3]

Dust emissions occur during conveying, screening, crushing, and storing operations. Because these materials are generally moist when handled, emissions are much lower than in a similar crushed stone operation. Sizeable emissions may also occur as vehicles travel over unpaved roads and paved roads covered by dirt. Although little actual source testing has been done, an estimate has been made for particulate emissions from a plant using crushers:

Particulate emissions: 0.1 lb/ton (0.05 kg/Mg) of product.[3]

References for Section 8.19

1. Walker, Stanton. Production of Sand and Gravel. National Sand and Gravel Association, Washington, DC. Circular Number 57. 1954.

2. Schreiber, William J. and H. H. Schenk. Evaluation of Dust and Noise Conditions at Typical Sand and Gravel Plants. Study conducted under the auspices of the Committee on Public Relations, National Sand and Gravel Association, by the Industrial Hygiene Foundation of America, Inc. 1958.

3. Particulate Pollutant System Study. Vol. I. Mass Emissions. Midwest Research Institute, Kansas City, Mo. Prepared for the Environmental Protection Agency, Research Triangle Park, N.C., under Contract Number CPA 22-69-104. May 1971.

8.20 STONE QUARRYING AND PROCESSING

8.20.1 Process Description[1]

Rock and crushed stone products are loosened by drilling and blasting them from their deposit beds and are removed with the use of heavy earth-moving equipment. This mining of rock is done primarily in open pits. The use of pneumatic drilling and cutting, as well as blasting and transferring, causes considerable dust formation. Further processing includes crushing, regrinding, and removal of fines.[2] Dust emissions can occur from all of these operations, as well as from quarrying, transferring, loading, and storage operations. Drying operations, when used, can also be a source of dust emissions.

8.20.2 Emissions[1]

As enumerated above, dust emissions occur from many operations in stone quarrying and processing. Although a big portion of these emissions is heavy particles that settle out within the plant, an effort has been made to estimate the suspended particulates. These emission factors are shown in Table 8.20.1. Factors affecting emissions include the amount of rock processed, the method of transfer of the rock, the moisture content of the raw material, the degree of enclosure of the transferring, processing, and storage areas, and the degree to which control equipment is used on the processes.

Table 8.20.1. PARTICULATE EMISSION FACTORS FOR ROCK HANDLING PROCESSES
EMISSION FACTOR RATING: C

Type of process	Uncontrolled total[a]		Settled out in plant, %	Suspended emission	
	lb/ton	kg/MT		lb/ton	kg/MT
Dry crushing operations[b,c]					
Primary crushing	0.5	0.25	80	0.1	0.05
Secondary crushing and screening	1.5	0.75	60	0.6	0.3
Tertiary crushing and screening (if used)	8	4	40	4.8	1.8
Recrushing and screening	5	2.5	50	2.5	1.25
Fines mill	8	3	25	4.5	2.25
Miscellaneous operations[d]					
Screening, conveying, and handling[e]	2	1			
Storage pile losses[f]					

[a] Typical collection efficiencies: cyclone, 70 to 86 percent; fabric filter, 99 percent.

[b] All values are based on raw material entering primary crusher, except those for secondary and tertiary crushing and fines mill, which are based on throughput for that operation.

[c] Reference 3.

[d] Based on tons of mined product.

[e] Reference 4.

[f] See section 11.2.3.

References for Section 8.20

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA 22-69-119. April 1970.

2. Communication between Resources Research, Incorporated, Reston, Virginia, and the National Crushed Stone Association. September 1969.

3. Culver, P. Memorandum to files. U.S. DHEW, PHS, National Air Pollution Control Administration, Division of Abatement, Durham, N.C. January 6, 1968.

4. Unpublished data on storage and handling of rock products. U.S. DHEW, PHS, National Air Pollution Control Administration, Division of Abatement, Durham, N.C. May 1967.

5. Stern, A. (ed.) In: Air Pollution, Vol. III, 2nd Ed. Sources of Air Pollution and Their Control. New York, Academic Press. 1968. p. 123-127.

9. PETROLEUM INDUSTRY

9.1 PETROLEUM REFINING

Revised by William M. Cavanagh

9.1.1 General

Although a modern refinery is a complex system of many processes, the entire operation can be divided into four major steps: separating, converting, treating, and blending. The crude oil is first separated into several fractions (e.g. gasoline, kerosene, fuel oil, etc.). Because the relative volumes of each fraction produced by merely separating the crude may not conform to the market demands for each fraction, some of the less valuable products, such as heavy naptha, are converted to products with a greater sale value, such as gasoline. This conversion is accomplished by splitting (cracking), uniting (polymerization), or rearranging (reforming) the original molecules. The final step is the blending of the refined base stocks with each other and with certain additives to meet final product specifications. The various unit operations involved in petroleum refineries will be briefly discussed in the following sections. A generalized petroleum refinery flow sheet is shown in Figure 9.1-1.

9.1.2 Crude Oil Distillation[1-5]

Crude oil is a mixture of many different hydrocarbons, many of them combined with small amounts of impurities. Crude oils vary considerably in composition and physical properties but generally consist of three families of hydrocarbons: paraffins, saturated hydrocarbons having the empirical formula C_nH_{2n+2}, representing structure saturated hydrocarbons with the formula C_nH_{2n}, and aromatics characterized by a benzene ring, C_6H_6, in the molecular structure. In addition to carbon and hydrogen, significant amounts of sulfur, oxygen, and nitrogen can be present in crude petroleum.

Separation of these hydrocarbon constituents into their respective fractions is performed by crude fractionation in crude topping or skimming units. Crude oil is heated in pipe stills and passed to fractionating towers or columns for vaporization and preparation. Heavy fractions of the crude oil, which do not vaporize in the column operation, are separated by steam or vacuum distillation. The heavy residuum products are subjected to coking and more valuable volatile products via destructive distillation and cracking. Depending on the desired range of the feed and its stability with respect to heat and product specifications, solvent extraction can be employed. Chemical treating can also be used. The distillation fractions (straight run products) usually include refinery gas, gasoline, kerosene, light fuel oil, diesel oils, gas oil, lube distillate, and heavy fuel/asphalt. The amount of each being determined by the type and composition of the crude. Some of these products are treated to remove impurities and used as base stocks or sold as finished products; the remainder are used as feedstocks for other refinery units.

9.1.2.1 Emissions. The main sources of emissions in crude oil preparation processes are the heaters, vents on the vacuum distillation columns, and condensers. Also contributing to the total emissions are the fugitive emissions from valves, pump seals, and flanges. Fugitive emissions consist of unburned light hydrocarbons and hydrogen sulfide in gas streams. The quantity of these emissions is a function of the refining type of feedstock and the refining unit operations. Table 9.1-1 presents refinery fugitive emissions before they undergo any control. Table 9.1-2 presents refinery stationary source emissions before they undergo any control. Table 9.1-3 presents refinery stationary source emissions after they undergo control. Table 9.1-4 presents refinery stationary source emissions reduced from uncontrolled to negligible amounts by control. Table 9.1-5 presents refinery stationary source emissions after they undergo control.

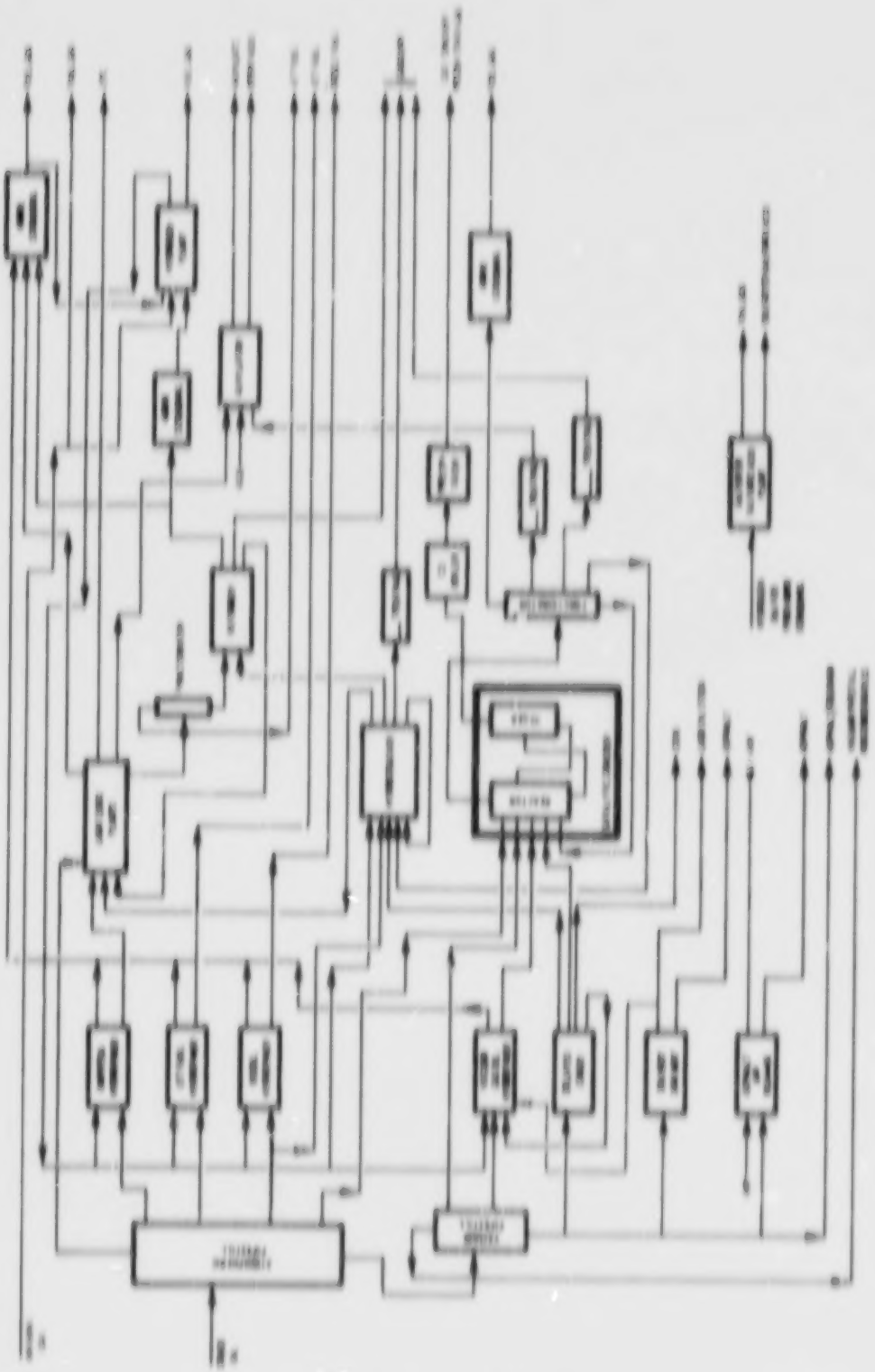

Figure 9.1-1. Basic oxygen furnace shop.

Table 5.1-1. EMISSION FACTORS FOR PETROLEUM REFINERIES
EMISSION FACTOR RATING: A

Type of process	Particulate	Sulfur oxides (SO_x)	Carbon monoxide	Hydrocarbons	Nitrogen oxides (NO_x)	Aldehydes	Ammonia
Boilers and process heaters[a]							
lb/10^3 bbl oil burned	840	6.7 (S)[b]	Negl[c]	140	2.8[d]	25	Negl
kg/10^3 liters oil burned	2.4	19 (S)	Negl	0.4	8.0	0.071	Negl
lb/10^3 ft^3 gas burned	0.02	2[e]	Negl	0.03	0.23	0.003	Negl
kg/10^3 m^3 gas burned	0.32	32	Negl	0.48	3.7	0.048	Negl
Fluid catalytic cracking units[f]							
Uncontrolled							
lb/10^3 bbl fresh feed	240 (80 to 340)[g]	460 (313 to 525)	13,700[h]	220	71.0 (37.1 to 145.0)	19	54
kg/10^3 liters fresh feed	0.685 (0.267 to 0.976)	1.413 (0.898 to 1.505)	39.2	0.630	0.204 (0.107 to 0.416)	0.054	0.155
Electrostatic precipitator and CO boiler							
lb/10^3 bbl fresh feed	44.7 (12.5 to 61.0)	460 (313 to 525)	Negl	220	71.0 (37.1 to 145.0)	19	54
kg/10^3 liters fresh feed	0.128 (0.036 to 0.175)	1.413 (0.898 to 1.505)	Negl	0.630	0.204 (0.107 to 0.416)	0.054	0.155
Moving bed catalytic cracking units[f]							
lb/10^3 bbl fresh feed	17	60	3,800	97	5	12	6
kg/10^3 liters fresh feed	0.049	0.171	10.8	0.278	0.014	0.034	0.017
Fluid coking units[f]							
Uncontrolled							
lb/10^3 bbl fresh feed	523	NA[i]	Negl	Negl	Negl	Negl	Negl
kg/10^3 liters fresh feed	1.50	NA	Negl	Negl	Negl	Negl	Negl
Electrostatic precipitator							
lb/10^3 bbl fresh feed	4.85	NA	Negl	Negl	Negl	Negl	Negl
kg/10^3 liters fresh feed	0.0138	NA	Negl	Negl	Negl	Negl	Negl

Table 9.1-1. (continued) EMISSION FACTORS FOR PETROLEUM REFINERIES

EMISSION FACTOR RATING: A

Type of source	Particulate	SO$_x$	Sulfuric acid mist	CO	Organics	Aldehydes	Ammonia	Chlorides	Fluorides	Lead	Arsenic	Cadmium	Chromium	Copper	Manganese	Nickel	Selenium	Zinc	Mercury	Beryllium
Compressor engines																				
Natural gas fired	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gasoline fired	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Diesel fired	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fluid coking	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Uncontrolled	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Controlled	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fluid cracking	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Uncontrolled	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Controlled

Table 9.1-1. (continued) EMISSION FACTORS FOR PETROLEUM REFINERIES

EMISSION FACTOR RATING: A

Type of process	Particulates	Sulfur oxides (SO_x)	Carbon monoxide	Hydrocarbons	Nitrogen oxides (NO_x)	Aldehydes	Ammonia
kg/10^3 liters vacuum distillate	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Cooling towers[2]							
lb/10^3 gal cooling water	Neg	Neg	Neg	C	Neg	Neg	Neg
kg/10^3 liters cooling water	Neg	Neg	Neg	0.72	Neg	Neg	Neg
Pipeline valves and flanges[2]							
lb/10^3 bbl refining capacity	Neg	Neg	Neg	28	Neg	Neg	Neg
kg/10^3 liters refining capacity	Neg	Neg	Neg	0.080	Neg	Neg	Neg
Vessel relief valves[2]							
lb/10^3 bbl refining capacity	Neg	Neg	Neg	77	Neg	Neg	Neg
kg/10^3 liters refining capacity	Neg	Neg	Neg	0.221	Neg	Neg	Neg
Pump seals[2]							
lb/10^3 bbl refining capacity	Neg	Neg	Neg	17	Neg	Neg	Neg
kg/10^3 liters refining capacity	Neg	Neg	Neg	0.049	Neg	Neg	Neg
Compressor seals[2]							
lb/10^3 bbl refining capacity	Neg Neg	Neg	Neg	5	Neg	Neg	Neg
kg/10^3 liters refining capacity	Neg	Neg	Neg	0.014	Neg	Neg	Neg
Miscellaneous (air blowing, sampling, etc.)[2]							
lb/10^3 bbl refining capacity	Neg	Neg	Neg	10	Neg	Neg	Neg
kg/10^3 liters refining capacity	Cert	Neg	Neg	0.029	Neg	Neg	Neg

[1]Reference 1.

[2]S_x = Fuel oil sulfur content (weight percent). Factors based on 100 percent combustion of sulfur to SO_2 and assumed density of 226 lb/bbl (0.96 kg/liter).

[3]Negligible emission.

[4]S_r = refinery gas sulfur content (lb/100 ft^3). Factors based on 100 percent combustion of sulfur to SO_2.

[5]References 1 through 6.

[6]Symbol = quantities indicate range or values observed.

[7]Reference 2.

9.1.3 Converting

To meet quantity demands for certain types of petroleum products, it is often necessary to chemically convert the molecular structures of certain hydrocarbons via "cracking" and "reforming" to produce compounds of different structures.

9.1.3.1 Catalytic Cracking[1] In the cracking operation, large molecules are decomposed by heat, pressure, and catalysis into smaller, lower-boiling molecules. Simultaneously, some of the molecules combine (polymerize) to form larger molecules. Products of cracking are gaseous hydrocarbons, gasoline, gas oil, fuel oil, and coke.

Most catalytic cracking operations in the U.S. today are performed by using four main methods: (1) fixed-bed, a batch operation; (2) moving-bed, typified by thermofor catalytic cracking (TCC) and Houdriflow units; (3) fluidized-bed (FCC); and (4) "once-through" units. The two most widely used units are the moving- and fluidized-bed types, with the latter most predominant.

In a moving-bed cracker, the charge (gas oil) is heated to 900°F under pressure and passed to the reactor where it passes cross-flow to a descending stream of molecular sieve-type catalyst in the form of beads or pellets. The cracked products then pass to a fractionating tower where the various compounds are tapped off. Meanwhile, the spent catalyst flows through a regeneration zone where coke deposits are burned off in a continuous process. The regenerated catalyst is then conveyed to storage bins atop the reactor vessel for reuse.

In fluidized systems, finely powdered catalyst is lifted into the reactor by the incoming heated oil charge, which vaporizes upon contact with the hot catalyst. Spent catalyst settles out in the reactor, is drawn off at a controlled rate, purged with steam, and lifted by an air stream into the regenerator where the deposited coke is burned off.

Emissions Emissions from cracking unit regenerators consist of particulates (coke and catalyst fines), hydrocarbons, sulfur oxides, carbon monoxide, aldehydes, ammonia, and nitrogen oxides in the combustion gases. In addition, catalyst fines may be discharged by vents on the catalyst handling systems on both FCC and TCC units. Control measures commonly used on regenerators consist of cyclones and electrostatic precipitators to remove particulates and energy recovery combustors to reduce carbon monoxide emissions. The latter recovers the heat of combustion of the CO to produce refinery process steam.

9.1.3.2 Hydrocracking[2] The hydrocracker uses a fixed-bed catalytic reactor, wherein cracking occurs in the presence of hydrogen under substantial pressure. The principal functions of the hydrogen are to suppress the formation of heavy, residual material and to increase the yield of gasoline by reacting with the cracked products. High-molecular-weight, sulfur-bearing hydrocarbons are also cracked, and the sulfur combines with the hydrogen to form hydrogen sulfide (H_2S). Therefore, waste gas from the hydrocracker contains large amounts of H_2S, which can be processed for removal of sulfur.

9.1.3.3 Catalytic Reforming[1] In reforming processes, a feedstock of gasoline undergoes molecular rearrangement via catalysis (usually including hydrogen removal) to produce a gasoline of higher quality and octane number. In various fixed-bed and fluidized-bed processes, the catalyst is regenerated continuously, in a manner similar to that used with cracking units.

There are essentially no emissions from reforming operations.

9.1.3.4 Polymerization, Alkylation, and Isomerization[1] Polymerization and alkylation are processes used to produce gasoline from the gaseous hydrocarbons formed during cracking operations. Polymerization joins two or

more olefins (monocyclic unsaturated hydrocarbons with C=C double bonds), and alkylation unites an olefin and an isoparaffin (monocyclic branched-chain hydrocarbon saturated with hydrogen). Isomerization is the process for altering the arrangement of atoms in a molecule without adding or removing anything from the original material, and is usually used in the oil industry to form branched-chain hydrocarbons. A number of catalysts such as phosphoric acid, sulfuric acid, platinum, aluminum chloride, and hydrofluoric acid are used to promote the combination or rearrangement of these light hydrocarbons.

9.1.3.5 Emissions. These three processes, including regeneration of any necessary catalysts, form essentially closed systems and have no unique, major source of atmospheric emissions. However, the highly volatile hydrocarbons handled, coupled with the high process pressures required, make valve stems and pump shafts difficult to seal, and a greater emission rate from these sources can generally be expected in these process areas than would be the average throughout the refinery. The best method for controlling these emissions is the effective maintenance, repair, and replacement of pump seals, valve caulking, and pipe joint sealer.

9.1.4 Treating

"Hydrogen," "chemical," and "physical" treating are used in the refinery process to remove undesirable impurities such as sulfur, nitrogen, and oxygen to improve product quality.

9.1.4.1 Hydrogen Treating[1]. In this procedure hydrogen is reacted with impurities in compounds to produce removable hydrogen sulfide, ammonia, and water. In addition, the process converts diolefins (gum-forming hydrocarbons with the empirical formula $R-C=C-R$) into stable compounds while minimizing saturation of desirable aromatics.

Hydrogenation units are nearly all the fixed-bed type with catalyst replacement or regeneration (by combustion) done intermittently, the frequency of which is dependent upon operating conditions and the product being treated. The hydrogen sulfide produced is removed from the hydrogen stream via extraction and converted to elemental sulfur or sulfuric acid or, when present in small quantities, burned to SO_2 in a flare or boiler firebox.

9.1.4.2 Chemical Treating[1]. Chemical treating is generally classified into four groups: (1) acid treatment, (2) sweetening, (3) solvent extraction, and (4) additives. Acid treatment involves contacting hydrocarbons with sulfuric acid to partially remove sulfur and nitrogen compounds, to precipitate asphaltic or gum-like materials, and to improve color and odor. Spent acid sludges that result are usually converted to ammonium sulfate or sulfuric acid.

Sweetening processes oxidize mercaptans (formula: R-S-H) to disulfide (formula: R-S-S-R) without actual sulfur removal. In some processes, air and steam are used for agitation in mixing tanks and to reactivate chemical solutions.

Solvent extraction utilizes solvents that have affinities for the undesirable compounds and that can easily be removed from the product stream. Specifically, mercaptan compounds are usually extracted using a strong caustic solution; hydrogen sulfide is removed by a number of commercial processes.

Finally, additives or inhibitors are primarily materials added in small amounts to oxidize mercaptans to disulfide and to retard gum formation.

9.1.4.3 Physical Treating[1] - Some of the many physical methods used to remove impurities include electrical coalescence, filtration, absorption, and air blowing. Specific applications of physical methods are desalting crude oil, removing wax, decolorizing lube oils, and brightening diesel oil.

9.1.4.4 Emissions - Emissions from treating operations consist of SO_2, hydrocarbons, and visible plumes. Emission levels depend on the methods used in handling spent acid and acid sludges, as well as the means employed for recovery or disposal of hydrogen sulfide. Other potential sources of these emissions in treating include catalyst regeneration, air agitation in mixing tanks, and other air blowing operations. Trace amounts of malodorous substances may escape from numerous sources including settling tank vents, purge tanks, waste treatment units, waste-water drains, valves, and pump seals.

Control methods used include: covers for waste water separators; vapor recovery systems for settling and surge tanks; improved maintenance for pumps, valves, etc.; and sulfur recovery plants.

9.1.5 Blending[1]

The final major operation in petroleum refining consists of blending the products in various proportions to meet certain specifications, such as vapor pressure, specific gravity, sulfur content, viscosity, octane number, initial boiling point, and pour point.

9.1.5.1 Emissions - Emissions associated with this operation are hydrocarbons that leak from storage vessels, valves, and pumps. Vapor recovery systems and specially built tanks minimize storage emissions; good housekeeping precludes pump and valve leakage.

9.1.6 Miscellaneous Operations[1]

In addition to the four refinery operations described above, there are many process operations connected with all four. These involve the use of cooling towers, blow-down systems, process heaters and boilers, compressors, and process drains. The emissions and controls associated with these operations are listed in Table 9.1.1.

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10. WOOD PROCESSING

Wood processing involves the conversion of raw wood to either pulp, pulpboard, or one of several types of wallboard including plywood, particleboard, or hardboard. This section presents emissions data for chemical wood pulping as well as for pulpboard and plywood manufacturing. The burning of wood waste in boilers and conical burners is not included as it is discussed in Chapters 1 and 2 of this publication.

10.1 CHEMICAL WOOD PULPING

Revised by: Thomas Lahre

10.1.1 General[1]

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The principal processes used in chemical pulping are the kraft, sulfite, neutral sulfite semichemical (NSSC), dissolving, and soda; the first three of these display the greatest potential for causing air pollution. The kraft process accounts for about 65 percent of all pulp produced in the United States; the sulfite and NSSC processes, together, account for less than 20 percent of the total. The choice of pulping process is determined by the product being made, by the type of wood species available, and by economic considerations.

10.1.2 Kraft Pulping

10.1.2.1 Process Description[1,2]—The kraft process (see Figure 10.1.2-1) involves the cooking of wood chips under pressure in the presence of a cooking liquor in either a batch or a continuous digester. The cooking liquor, or "white liquor," consisting of an aqueous solution of sodium sulfide and sodium hydroxide, dissolves the lignin that binds the cellulose fibers together.

When cooking is completed, the contents of the digester are forced into the blow tank. Here the major portion of the spent cooking liquor, which contains the dissolved lignin, is drained, and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter where unreacted chunks of wood are removed. The pulp is then washed and, in some mills, bleached before being pressed and dried into the finished product.

It is economically necessary to recover both the inorganic cooking chemicals and the heat content of the spent "black liquor," which is separated from the cooked pulp. Recovery is accomplished by first concentrating the liquor to a level that will support combustion and then feeding it to a furnace where burning and chemical recovery take place.

Initial concentration of the weak black liquor, which contains about 15 percent solids, occurs in the multiple-effect evaporator. Here process steam is passed countercurrent to the liquor in a series of evaporator tubes that increase the solids content to 40 to 55 percent. Further concentration is then effected in the direct contact evaporator. This is generally a scrubbing device (a cyclonic or venturi scrubber or a cascade evaporator) in which hot combustion gases from the recovery furnace mix with the incoming black liquor to raise its solids content to 55 to 70 percent.

The black liquor concentrate is then sprayed into the recovery furnace where the organic content supports combustion. The inorganic compounds fall to the bottom of the furnace and are discharged to the smelt dissolving tank to form a solution called "green liquor." The green liquor is then conveyed to a causticizer where slaked lime (calcium hydroxide) is added to convert the solution back to white liquor, which can be reused in subsequent cooks. Residual lime sludge from the causticizer can be recycled after being dewatered and calcined in the lime kiln.

Many mills need more steam for process heating, for driving equipment, for providing electric power, etc., than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, and in some cases, bark and wood waste are commonly employed.

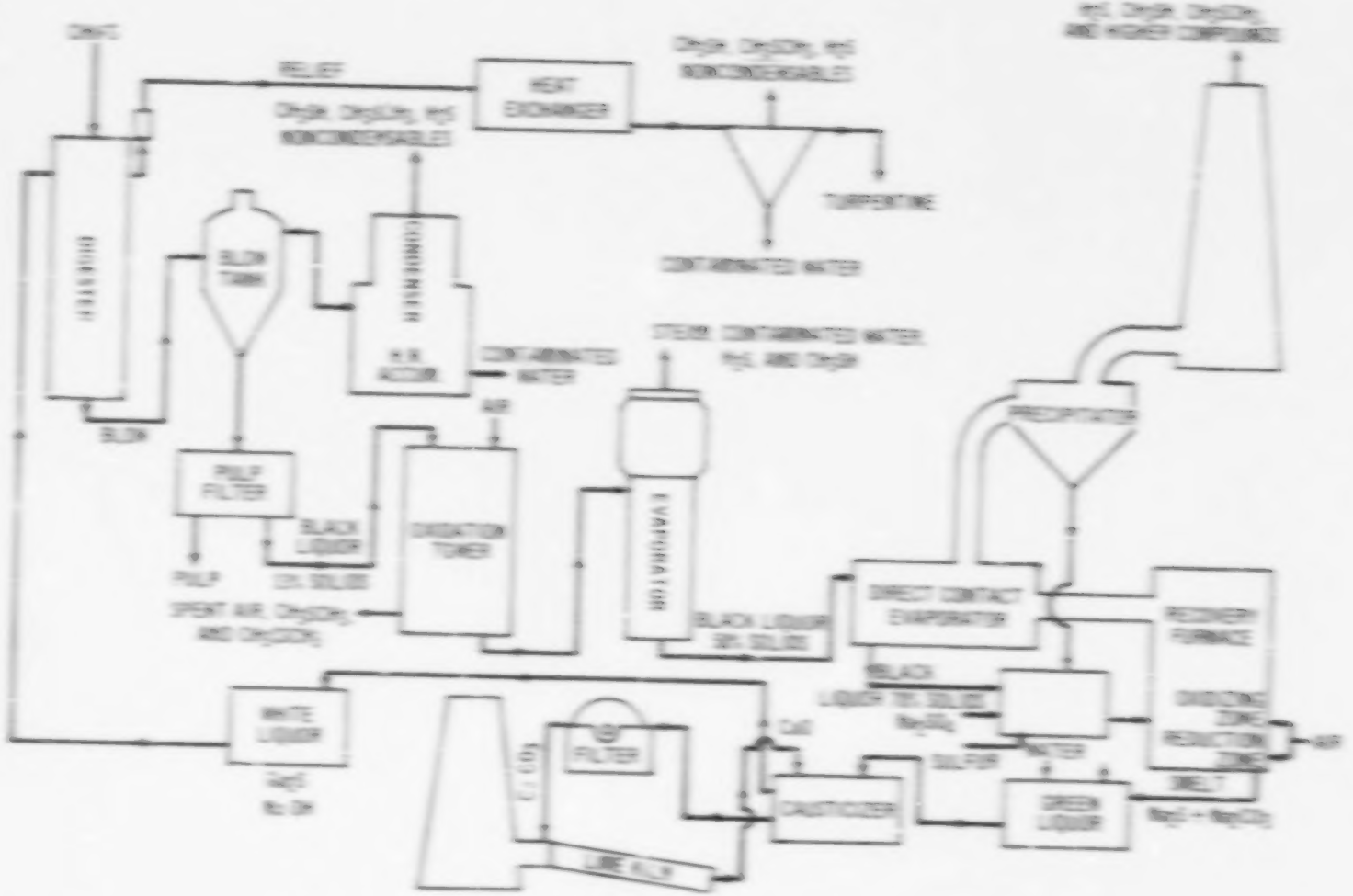

Figure 10.1.2-1. Typical kraft sulfate pulp mfg and recovery process.

10.1.3.3 Emission and Controls[1-6] Particulate emissions from the kraft process occur primarily from the recovery furnace, the lime kiln, and the smelt dissolving tank. These emissions consist mainly of sodium salts but include some calcium salts from the lime kiln. They are caused primarily by the carryover of solids plus the sublimation and condensation of the inorganic chemicals.

Particulate control is provided on recovery furnaces in a variety of ways. In mills where either a cyclonic scrubber or cascade evaporator serves as the direct contact evaporator, further control is necessary as these devices are generally only 20 to 50 percent efficient for particulates. Most often in these cases, an electrostatic precipitator is employed after the direct contact evaporator to provide an overall particulate control efficiency of 85 to ≥ 99 percent. In a few mills, however, a venturi scrubber is utilized as the direct contact evaporator and simultaneously provides 80 to 90 percent particulate control. In either case auxiliary scrubbers may be included after the precipitator or the venturi scrubber to provide additional control of particulates.

Particulate control on lime kilns is generally accomplished by scrubbers. Smelt dissolving tanks are commonly controlled by mesh pads but employ scrubbers when further control is needed.

The characteristic odor of the kraft mill is caused in large part by the emission of hydrogen sulfide. The major source is the direct contact evaporator in which the sodium sulfide in the black liquor reacts with the carbon dioxide in the furnace exhaust. The lime kiln can also be a potential source as a similar reaction occurs involving residual sodium sulfide in the lime mud. Lesser amounts of hydrogen sulfide are emitted with the noncondensable off gases from the digesters and multiple-effect evaporators.

The kraft process odor also results from an assortment of organic sulfur compounds, all of which have extremely low odor thresholds. Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignin. These compounds are emitted from many points within a mill; however, the main sources are the digester/blow tank systems and the direct contact evaporator.

Although odor control devices, per se, are not generally employed in kraft mills, control of reduced sulfur compounds can be accomplished by process modifications and by optimizing operating conditions. For example, black liquor oxidation systems, which oxidize sulfides into less reactive thiosulfates, can considerably reduce odorous sulfur emissions from the direct contact evaporator, although the vent gases from such systems become minor odor sources themselves. Noncondensable odorous gases vented from the digester/blow tank system and multiple-effect evaporators can be destroyed by thermal oxidation, usually by passing them through the lime kiln. Optimum operation of the recovery furnace, by avoiding overloading and by maintaining sufficient oxygen residual and turbulence, significantly reduces emissions of reduced sulfur compounds from this source. In addition, the use of fresh water instead of contaminated condensates in the scrubbers and pulp washers further reduces odorous emissions. The effect of any of these modifications on a given mill's emissions will vary considerably.

Several new mills have incorporated recovery systems that eliminate the conventional direct contact evaporators. In one system, preheated combustion air rather than flue gas provides direct contact evaporation. In the other, the multiple effect evaporator system is extended to replace the direct contact evaporator altogether. In both of these systems, reduced sulfur emissions from the recovery furnace/direct contact evaporator reportedly can be reduced by more than 95 percent from conventional uncontrolled systems.

Sulfur dioxide emissions result mainly from oxidation of reduced sulfur compounds in the recovery furnace. It is reported that the direct contact evaporator absorbs 50 to 80 percent of these emissions; further scrubbing, if employed, can reduce them another 10 to 20 percent.

Potential sources of carbon monoxide emissions from the kraft process include the recovery furnace and lime kilns. The major cause of carbon monoxide emissions is furnace operation well above rated capacity, making it impossible to maintain oxidizing conditions.

Some nitrogen oxides are also emitted from the recovery furnace and lime kilns although the amounts are relatively small. Indications are that nitrogen oxides emissions from each of these sources are on the order of 1 pound per air dried ton (0.5 kg/air dried MT) of pulp produced.[5,6]

A major source of emissions in a kraft mill is the boiler for generating auxiliary steam and power. The fuels used are coal, oil, natural gas, or bark/wood waste. Emission factors for boilers are presented in Chapter 1.

Table 10.1.3-1 presents emission factors for a conventional kraft mill. The most widely used particulate controls devices are shown along with the odor reductions resulting from black liquor oxidation and incineration of noncondensable off gases.

10.1.3 Acid Sulfite Pulping

10.1.3.1 Process Description[1-3,14-16] The production of acid sulfite pulp proceeds similarly to kraft pulping except that different chemicals are used in the cooking liquor. In place of the caustic solution used to dissolve the lignin in the wood, a sulfurous acid base is employed. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium, or ammonium is used.

Because of the variety of bases employed in the cooking liquor, numerous schemes for heat and/or chemical recovery have evolved. In calcium-base systems, which are used mostly in older mills, chemical recovery is not practical, and the spent liquor is usually discarded. In ammonium-base operations, heat can be recovered from the spent liquor through combustion, but the ammonium base is consumed in the process. In sodium- or magnesium-base operations (the latter being utilized most frequently in newer sulfite mills) heat, sulfur, and base recovery are all feasible.

When recovery is practiced, the spent liquor proceeds through a multiple-effect evaporator and recovery furnace arrangement similar to that found in the kraft process. The combustion gases from the furnace pass through absorbing (sulfiting) towers where sulfur dioxide is recovered (as bisulfite) for use in subsequent cooks. In magnesium- or sodium-base operations, moreover, the base can also be recovered by feeding the inorganic residue from the furnace (either as smelt or collected ash) into the absorbing tower to react with the sulfur dioxide.

10.1.3.2 Emission and Controls[1,3,14-16] Significant quantities of particulate emissions will be generated only if sodium-, magnesium-, or calcium-base liquors are burned. When ammonium-base liquor is burned, few particulates will result because the combustion products are mostly nitrogen, water vapor, and sulfur dioxide. In magnesium-base recovery systems, high particulate control is necessary because most of the base is swept out of the furnace in the form of magnesium oxide fumes. No particulate emissions will result from these systems, of course, when the spent liquor is not combusted.

The major gaseous pollutant is sulfur dioxide. Major potential sources, in probable order of importance, include the digester/blow tank system, absorbing towers, and multiple-effect evaporators. Because the vented gases from these systems are either scrubbed or fed into the absorbing tower to minimize sulfur losses, actual emissions to the atmosphere will depend on the degree of efficiencies desired.

The characteristic "kraft" odor is not emitted from acid sulfite mills because volatile reduced sulfur compounds are not products of the lignin-bisulfite reaction.

No factors for sulfite pulping are presented because of the variety of pulping schemes employed and lack of adequate emissions data.

10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping

10.1.4.1 Process Description[1,3,14,17] In this process, the wood chips are cooked in a neutral solution of sodium sulfite and sodium bicarbonate. The sulfite ion reacts with the lignin in the wood, and the sodium bicarbonate

Table 10.1.2-1. EMISSION FACTORS FOR SULFATE PULPING[a]
(unit weights of air-dried unbleached pulp)
EMISSION FACTOR RATING: A

Source	Type control	Particulate[b] lb/ton	Particulate[b] kg/MT	Sulfur dioxide (SO_2)[c] lb/ton	Sulfur dioxide (SO_2)[c] kg/MT	Carbon monoxide[d] lb/ton	Carbon monoxide[d] kg/MT	Hydrogen sulfide[e,f] lb/ton	Hydrogen sulfide[e,f] kg/MT	RSH, RSR, RSSR[e,f,g,h] lb/ton	RSH, RSR, RSSR[e,f,g,h] kg/MT
Digester relief and blow tank	Uncontrolled[i]	—	—	—	—	—	—	0.7	0.35	1.5	0.75
Brown stock washers	Uncontrolled	—	—	0.27	0.135	—	—	0.02	0.01	0.2	0.1
Multiple-effect evaporators	Uncontrolled[j]	—	—	0.01	0.005	—	—	0.1	0.05	0.4	0.2
Recovery boiler and direct contact evaporator	Uncontrolled[k]	150	75	5	2.5	2 - 60	1 - 30	12[l]	6[l]	1[l]	0.5[l]
	Venturi scrubber[m]	40	20.5	5	2.5	2 - 60	1 - 30	12[l]	6[l]	1[l]	0.5[l]
	Electrostatic precipitator	8	4	5	2.5	2 - 60	1 - 30	12[l]	6[l]	1[l]	0.5[l]
	Auxiliary scrubber	3 - 10[n]	1.5 - 7.5[n]	5	2.5	2 - 60	1 - 30	12[l]	6[l]	1[l]	0.5[l]
Smelt dissolving tank	Uncontrolled	5	2.5	0.1	0.05	—	—	0.04	0.02	0.4	0.2
	Mesh pad	1	0.5	0.1	0.05	—	—	0.04	0.02	0.4	0.2
Lime kilns	Uncontrolled	45	22.5	0.3	0.15	10	5	0.5	0.25	0.25	0.125
	Scrubber	3	1.5	0.2	0.1	10	5	0.5	0.25	0.25	0.125
Turpentine condenser	Uncontrolled	—	—	—	—	—	—	0.07	0.035	0.5	0.25
Miscellaneous sources[o]	Uncontrolled	—	—	—	—	—	—	—	—	0.5	0.25

[a] For more detailed data on specific types of mills, consult Reference 1.

[b] References 1, 7, 8.

[c] References 1, 7, 8, 10.

[d] References 8, 11. Use higher value for oversloped furnaces.

[e] References 1, 4, 7-10, 12, 13. These reduced sulfur compounds are usually expressed as sulfur.

[f] RSH methyl mercaptan, RSR dimethyl sulfide, RSSR dimethyl disulfide.

[g] For the noncondensible gases from these sources are vented to the lime kiln, recovery furnace, or equivalent, the reduced sulfur compounds are destroyed.

[h] These factors apply when either a cyclonic scrubber or cascade evaporator is used for direct contact evaporation with no further controls.

[i] These reduced sulfur compounds, TRS, are typically reduced to 50 percent when black liquor oxidation is employed but can be cut by 90 to 99 percent when oxidation is complete and the recovery furnace is operated optimally.

[j] These factors apply when a venturi scrubber is used for direct contact evaporation with no further controls.

[k] Use 15.0 [7.5] when the auxiliary scrubber follows a venturi or, other and 37.5 [18.75] when employed after an electrostatic precipitator.

[l] Includes smelter vents, evaporators and tanks, etc. When black liquor oxidation is included, a factor of 1.5 [0.75] should be used.

acts as a buffer to maintain a neutral solution. The major difference between this process (as well as all semi-chemical techniques) and the kraft and acid sulfite processes is that only a portion of the lignin is removed during the cook, after which the pulp is further reduced by mechanical disintegration. Because of this, yields as high as 65 to 80 percent can be achieved as opposed to 50 to 55 percent for other chemical processes.

The NSSC process varies from mill to mill. Some mills dispose of their spent liquor, some mills recover the cooking chemicals, and some, which are operated in conjunction with kraft mills, mix their spent liquor with the kraft liquor as a source of makeup chemicals. When recovery is practiced, the steps involved parallel those of the sulfite process.

10.1.3 Emissions and Controls[1-3,5] Particulate emissions are a potential problem only when recovery systems are employed. Mills that do practice recovery, but are not operated in conjunction with kraft operations often utilize fluidized bed reactors to burn their spent liquor. Because the flue gas contains sodium sulfate and sodium carbonate dust, efficient particulate collection may be included to facilitate chemical recovery.

A potential gaseous pollutant is sulfur dioxide. The absorbing towers, digester/blow tank system, and recovery furnace are the main sources of this pollutant with the amounts emitted dependent upon the capability of the scrubbing devices installed for control and recovery.

Hydrogen sulfide can also be emitted from NSSC mills using kraft type recovery furnaces. The main potential source is the absorbing tower where a significant quantity of hydrogen sulfide is liberated as the cooking liquor is made. Other possible sources include the recovery furnace, depending on the operating conditions maintained, as well as the digester/blow tank system in mills where some green liquor is used in the cooking process. Where green liquor is used, it is also possible that significant quantities of mercaptans will be produced. Hydrogen sulfide emissions can be eliminated if burned to sulfur dioxide prior to entering the absorbing systems.

Because the NSSC process differs greatly from mill to mill, and because of the scarcity of adequate data, no emission factors are presented.

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10.2 PULPBOARD

10.2.1 General[1]

Pulpboard manufacturing involves the fabrication of fibrous boards from a pulp slurry. This includes two distinct types of product, paperboard and fiberboard. Paperboard is a general term that describes a sheet 0.012 inch (0.30 mm) or more in thickness made of fibrous material on a paper-forming machine.[2] Fiberboard, also referred to as particle board, is thicker than paperboard and is made somewhat differently.

There are two distinct phases in the conversion of wood to pulpboard: (1) the manufacture of pulp from raw wood and (2) the manufacture of pulpboard from the pulp. This section deals only with the latter as the former is covered under the section on the wood pulping industry.

10.2.2 Process Description[1]

In the manufacture of paperboard, the stock is sent through screens into the head box, from which it flows onto a moving screen. Approximately 15 percent of the water is removed by suction boxes located under the screen. Another 50 to 60 percent of the moisture content is removed in the drying section. The dried board then enters the calendar stack, which imparts the final surface to the product.

In the manufacture of fiberboard, the slurry that remains after pulping is washed and sent to the stock chests where sizing is added. The refined fiber from the stock chests is fed to the head box of the board machine. The stock is next fed onto the forming screens and sent to dryers, after which the dry product is finally cut and fabricated.

10.2.3 Emissions[1]

Emissions from the paperboard machine consist mainly of water vapor; little or no particulate matter is emitted from the dryers.[1,3] Particulates are emitted, however, from the fiberboard drying operation. Additional particulate emissions occur from the cutting and sanding operations, but no data are available to estimate these emissions. Emission factors for pulpboard manufacturing are shown in Table 10.2.1.

Table 10.2.1. PARTICULATE EMISSION FACTORS FOR PULPBOARD MANUFACTURING[a]
EMISSION FACTOR RATING: E

Type of product	Emissions	
	lb/ton	kg/MT
Paperboard	Neg	Neg
Fiberboard[b]	0.6	0.3

[a]Emission factors expressed as units per unit weight of finished product.
[b]Reference 1.

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10.1 PLYWOOD VENEER AND LAYOUT OPERATIONS

By Thomas Lahre

10.1.1 Process Description[1]

Plywood is a material made of several thin wood veneers bonded together with an adhesive. Its uses are many and include wall sidings, sheathing, roof decking, concrete formboards, floors, and containers.

During the manufacture of plywood, incoming logs are sawed to desired length, debarked, and then peeled into thin, continuous veneers of uniform thickness. (Veneer thicknesses of 1/45 to 1/5 inch are common.) These veneers are then transported to special dryers where they are subjected to high temperatures until dried to a desired moisture content. After drying, the veneers are sorted, patched, and assembled in layers with some type of thermosetting resin used as the adhesive. The veneer assembly is then transferred to a hot press where, under pressure and steam heat, the plywood product is formed. Subsequently, all that remains is trimming, sanding, and possibly some sort of finishing treatment to enhance the usefulness of the plywood.

10.1.2 Emissions[2-3]

The main sources of emissions from plywood manufacturing are the veneer drying and sanding operations. A third source is the pressing operation although these emissions are considered minor.

The major pollutants emitted from veneer dryers are organics. These consist of two discernable fractions: (1) condensibles, consisting of wood resins, resin acids, and wood sugars, which form a blue haze upon cooling in the atmosphere, and (2) volatiles, which are comprised of terpines and unburned methane - the latter occurring when gas-fired dryers are employed. The amounts of these compounds produced depends on the wood species dried, the drying time, and the nature and operation of the dryer itself. In addition, negligible amounts of fine wood fibers are also emitted during the drying process.

Sanding operations are a potential source of particulate emissions. It is estimated that about 1,000 pounds of sanderdust may result for every 10,000 square feet of plywood produced. Hence, even if only a fraction of this is discharged to the atmosphere, an air pollution problem may exist. Few data exist to determine the actual magnitude of these emissions although efficient cyclonic collectors reportedly remove large portions of this dust.

Emission factors for plywood veneer dryers without controls are given in Table 10.1-1.

Table 10.1-1. EMISSION FACTORS FOR PLYWOOD MANUFACTURING
EMISSION FACTOR RATING: B

Source	Organic compounds[a,b]			
	Condensible		Volatile	
	lb/10^3 ft^2	kg/10^3 m^2	lb/10^3 ft^2	kg/10^3 m^2
Veneer dryers	3.6	1.9	2.1	1.1

[a] Emission factors expressed in pounds of pollutant per 10,000 square feet of 3/8 in. plywood produced (kilograms per 1,000 square meter on a 1 cm basis).

[b] References 2 and 3.

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MISCELLANEOUS SOURCES

This chapter contains emission factor information on those source categories that differ substantially from—and hence cannot be grouped with—the other "stationary" sources discussed in this publication. These "miscellaneous" emitters (both natural and man-made) are almost exclusively "area sources"—that is, their pollutant generating process(es) are dispersed over large land areas (for example, hundreds of acres, as in the case of forest wildfires), as opposed to sources emitting from one or more stacks with a total emitting area of only several square feet. Another characteristic these sources have in common is the nonapplicability, in most cases, of conventional control methods, such as wet/dry equipment, fuel switching, process changes, etc. Instead, control of these emissions, where possible at all, may include such techniques as modification of agricultural burning practices, paving with asphalt or concrete, or stabilization of dirt roads. Finally, miscellaneous sources generally emit pollutants intermittently, when compared with most stationary point sources. For example, a forest fire may emit large quantities of particulates and carbon monoxide for several hours or even days, but when measured against the emissions of a continuous emitter (such as a sulfuric acid plant) over a long period of time (1 year, for example), its emissions may seem relatively minor. Effects on air quality may also be of relatively short-term duration.

11.1 FOREST WILDFIRES

by William M. Vatavuk, EPA
and George Yamate, III (Consultant)

11.1.1 General[1]

A forest "wildfire" is a large-scale natural combustion process that consumes various ages, sizes, and types of botanical specimens growing outdoors in a defined geographical area. Consequently, wildfires are potential sources of large amounts of air pollutants that should be considered when trying to relate emissions to air quality.

The size and intensity (or even the occurrence) of a wildfire is directly dependent on such variables as the local meteorological conditions, the species of trees and their moisture content, and the weight of consumable fuel per acre (fuel loading). Once a fire begins, the dry combustible material (usually small undergrowth and forest floor litter) is consumed first, and if the energy release is large and of sufficient duration, the drying of green, live material occurs with subsequent burning of this material as well as the larger dry material. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

The complete combustion of a forest fuel will require a heat flux (temperature gradient), an adequate oxygen supply, and sufficient burning time. The size and quantity of forest fuels, the meteorological conditions, and the topographic features interact to modify and change the burning behavior as the fire spreads; thus, the wildfire will attain different degrees of combustion during its lifetime.

The importance of both fuel type and fuel loading on the fire process cannot be overemphasized. To meet the pressing need for this kind of information, the U.S. Forest Service is developing a country-wide fuel identification system (model) that will provide estimates of fuel loading by tree size class, in tons per acre. Further, the environmental parameters of wind, slope, and expected moisture changes have been superimposed on this fuel model and incorporated into a National Fire Danger Rating System (NFDRS). This system considers five classes of fuel (three dead and two living), the components of which are selected on the basis of combustibility, response to moisture (for the dead fuels), and whether the living fuels are herbaceous (plants) or ligneous (trees).

Most fuel loading figures are based on values for "available fuel" (combustible material that will be consumed in a wildfire under specific weather conditions). Available fuel values must not be confused with corresponding values for either "total fuel" (all the combustible material that would burn under the most severe weather and burning

conditions) or "potential fuel" (the larger woody material that remains even after an extremely high intensity wildfire). It must be emphasized, however, that the various methods of fuel identification are of value only when they are related to the existing fuel quantity, the quantity consumed by the fire, and the geographic area and conditions under which the fire occurs.

For the sake of conformity (and convenience), estimated fuel loadings were obtained for the vegetation in the National Forest Regions and the wildlife areas established by the U.S. Forest Service, and are presented in Table 11.1.1. Figure 11.1.1 illustrates these areas and regions.

Table 11.1.1. SUMMARY OF ESTIMATED FUEL CONSUMED BY FOREST FIRES[a]

Area and Region[b]		Estimated average fuel loading	
		Mt/hectare	ton/acre
Rocky Mountain group		83	37
Region 1:	Northern	175	60
Region 2:	Rocky Mountain	67	30
Region 3:	Southwestern	22	10
Region 4:	Intermountain	40	8
Pacific group		44	19
Region 5:	California	40	18
Region 6:	Pacific Northwest	135	60
Region 10:	Alaska	36	16
	Coastal	135	60
	Interior	25	11
Southern group		20	9
Region 8:	Southern	20	9
Eastern group		25	11
North Central group		25	11
Region 9:	Conifers	22	10
	Hardwoods	27	12

[a]Reference 1.

[b]See Figure 11.1.1 for regional boundaries.

11.1.2 Emissions and Controls[1]

It has been hypothesized (but not *proven*) that the nature and amounts of air pollutant emissions are directly related to the intensity and direction (relative to the wind) of the wildfire, and indirectly related to the rate at which the fire spreads. The factors that affect the rate of spread are (1) weather (wind velocity, ambient temperature, and relative humidity), (2) fuels (fuel type, fuel bed array, moisture content, and fuel size), and (3) topography (slope and profile). However, logistical problems (such as size of the burning area) and difficulties in safely situating personnel and equipment close to the fire have prevented the collection of any reliable experimental emission data on actual wildfires, so that it is presently impossible to verify or disprove the above-stated hypothesis. Therefore, until such measurements are made, the only available information is that

Figure 11.1-1. Forest areas and U.S. Forest Service Regions.

obtained from burning experiments in the laboratory. These data, in the forms of both emissions and emission factors, are contained in Table 11.1-3. It must be emphasized that the factors presented here are adequate for laboratory-scale emissions estimates, but that substantial errors may result if they are used to calculate actual wildfire emissions.

The emissions and emission factors displayed in Table 11.1-3 are calculated using the following formulas:

$$F_i = P_i L \quad (1)$$

$$E_i = F_i A = P_i L A \quad (2)$$

where: F_i = Emission factor (mass of pollutant/unit area of forest consumed)

P_i = Yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)

= 8.5 kg/MT (17 lb/ton) for total particulate

= 70 kg/MT (140 lb/ton) for carbon monoxide

= 12 kg/MT (24 lb/ton) for total hydrocarbon (as CH_4)

Table 11.1-2. SUMMARY OF EMISSIONS AND EMISSION FACTORS FOR FOREST WILDFIRES[a]
EMISSION FACTOR RATING: D

Geographic area[b]	Area consumed by wildfire, hectares	Wildfire fuel consumption, MT/hectare	Emission factors, kg/hectare				Emissions, MT			
			Particulate	Carbon monoxide	Hydrocarbons	Nitrogen oxides	Particulate	Carbon monoxide	Hydrocarbons	Nitrogen oxides
Rocky Mountain group	312,397	60	786	5,810	946	166	220,907	1,816,237	311,869	51,878
Northern, Region 1	142,276	135	1,144	9,420	1,520	269	162,529	1,339,393	229,592	38,265
Rocky Mountain, Region 2	65,882	67	570	4,710	836	135	37,554	310,284	53,157	8,892
Southwestern, Region 3	82,765	22	197	1,570	359	45	16,957	121,417	22,523	3,735
Intermountain, Region 4	21,475	40	153	1,260	215	36	3,273	26,953	4,638	770
Pacific group	464,998	43	362	2,985	512	85	170,096	1,406,728	240,128	40,071
California, Region 5	18,997	40	340	2,830	485	81	6,514	53,645	9,198	1,533
Alaska, Region 10	423,530	36	305	2,510	431	72	129,598	1,062,154	182,255	30,376
Pacific N.W. Region 6	27,390	135	1,144	9,420	1,620	269	31,296	257,728	44,182	7,363
Southern group	806,299	20	172	1,410	242	40	138,244	1,136,484	195,168	32,528
Southern, Region 8	806,299	20	172	1,410	242	40	138,244	1,136,484	195,168	32,528
North Central group	94,197	35	210	1,730	296	49	19,738	162,970	27,867	4,644
Eastern, Region 9	141,238	35	210	1,730	296	49	29,648	242,746	41,785	6,964
(Both groups are in Region 9)										
Eastern group (With Region 9)	47,046	35	210	1,730	296	49	9,859	81,391	13,918	2,320
Total United States	1,730,230	38	324	2,670	458	76	560,552	4,616,317	791,368	131,895

[a] Areas consumed by wildfire and emissions per Ito 1971.

[b] Geographic areas are defined in Figure 11.1-1.

[c] Hydrocarbons expressed as methane.

= 7 kg/MT (14 lb/ton) for nitrogen oxides (NO_x)

= Negligible for sulfur oxides (SO_x)

L = Fuel loading consumed (mass of forest fuel/unit land area burned)

A = Land area burned

E_i = Total emissions of pollutant "i" (mass of pollutant)

For example, suppose that it is necessary to estimate the total particulate emissions from a 10,000 hectare wildfire in the Southern area (Region 8). From Table 11.1-1 it is seen that the average fuel loading is 20 MT/hectare (9 ton/acre). Further, the pollutant yield for particulates is 8.5 kg/MT (17 lb/ton). Therefore, the emissions are:

E = (8.5 kg/MT of fuel) (20 MT of fuel/hectare) (10,000 hectares)

E = 1,700,000 kg = 1,700 MT

The most effective method for controlling wildfire emissions is, of course, to prevent the occurrence of forest fires using various means at the forester's disposal. A frequently used technique for reducing wildfire occurrence is "prescribed" or "hazard reduction" burning. This type of managed burn involves combustion of litter and underbrush in order to prevent fuel buildup on the forest floor and thus reduce the danger of a wildfire. Although some air pollution is generated by this preventative burning, the net amount is believed to be a relatively smaller quantity than that produced under a wildfire situation.

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11.2 FUGITIVE DUST SOURCES

by Charles O. Mann, EPA,
and Chatten C. Cowherd, Jr.,
Midwest Research Institute

Significant sources of atmospheric dust arise from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Common sources of fugitive dust include: (1) unpaved roads, (2) agricultural tilling operations, (3) aggregate storage piles, and (4) heavy construction operations.

For the above categories of fugitive dust sources, the dust generation process is caused by two basic physical phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.).

2. Entrainment of dust particles by the action of turbulent air currents. Airborne dust may also be generated independently by wind erosion of an exposed surface if the wind speed exceeds about 12 mi/hr (19 km/hr).

The air pollution impact of a fugitive dust source depends on the quantity and drift potential of the dust particles injected into the atmosphere. In addition to large dust particles that settle out near the source (often creating a localized nuisance problem), considerable amounts of fine particles are also emitted and dispersed over much greater distances from the source.

Control techniques for fugitive dust sources generally involve watering, chemical stabilization, or reduction of surface wind speed using windbreaks or source enclosures. Watering, the most common and generally least expensive method, provides only temporary dust control. The use of chemicals to treat exposed surfaces provides longer term dust suppression but may be costly, have adverse impacts on plant and animal life, or contaminate the treated material. Windbreaks and source enclosures are often impractical because of the size of fugitive dust sources. At present, too few data are available to permit estimation of the control efficiencies of these methods.

11.2.1 Unpaved Roads (Dirt and Gravel)

11.2.1.1 General. Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels over an unpaved road, the force of the wheels on the road surface cause pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

11.2.1.2 Emissions and Correction Parameters. The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. In addition, emissions depend on correction parameters (average vehicle speed, vehicle mix, surface texture, and surface moisture) that characterize the condition of a particular road and the associated vehicular traffic.

In the typical speed range on unpaved roads, that is, 30-50 mi/hr (48-80 km/hr), the results of field measurements indicate that emissions are directly proportional to vehicle speed.[1-3] Limited field measurements further indicate that vehicles produce dust from an unpaved road in proportion to the number of wheels.[1] For roads with a significant volume of vehicles with six or more wheels, the traffic volume should be adjusted to the equivalent volume of four-wheeled vehicles.

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (that is, particles smaller than 75 μm in diameter as defined by American Association of State Highway Officials) in the road surface material.[1] The silt fraction is determined by measuring the proportion of loose, dry, surface dust

that passes a 200-mesh screen. The silt content of gravel roads averages about 12 percent, and the silt content of a dirt road may be approximated by the silt content of the parent soil in the area.[1]

Unpaved roads have a hard, nonporous surface that dries quickly after a rainfall. The temporary reduction in emissions because of rainfall may be accounted for by neglecting emissions on "wet" days, that is, days with more than 0.01 in. (0.254 mm) of rainfall.

11.2.1.3 Corrected Emission Factor. The quantity of fugitive dust emissions from an unpaved road, per vehicle mile of travel, may be estimated (within ± 30 percent) using the following empirical expression[1]:

$$E = \left(0.81\,s\right)\left(\frac{S}{30}\right)\left(\frac{365 - w}{365}\right) \qquad (1)$$

where: E = Emission factor, pounds per vehicle mile

s = Silt content of road surface material, percent

S = Average vehicle speed, miles per hour

w = Mean annual number of days with 0.01 in. (0.254 mm) or more of rainfall (see Figure 11.2-1)

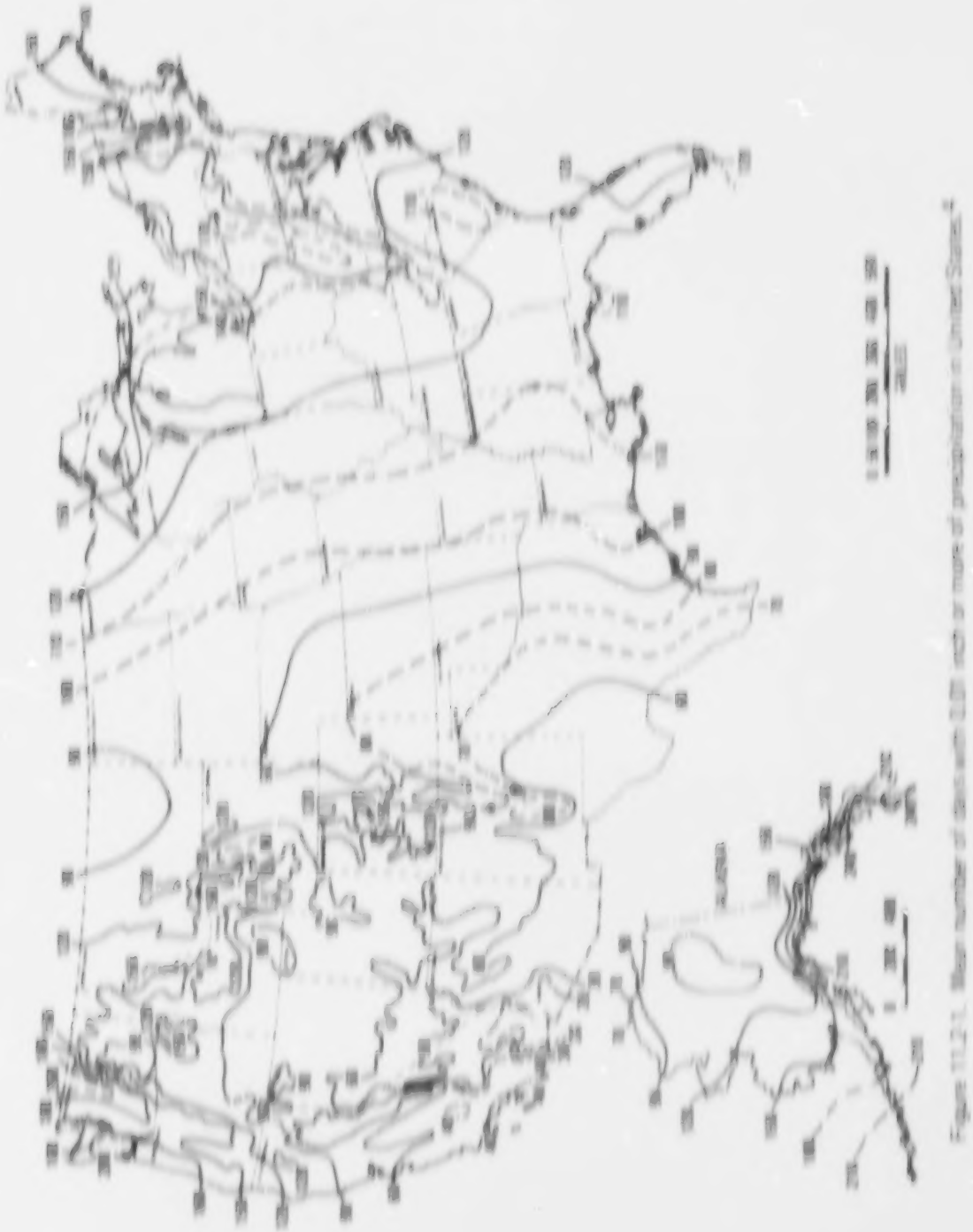
The equation is valid for vehicle speeds in the range of 30-50 mi/hr (48-80 km/hr).

On the average, dust emissions from unpaved roads, as given by equation 1, have the following particle size characteristics:[1]

Particle size	Weight percent
< 30 μm	60
> 30 μm	40

The 30 μm value was determined[1] to be the effective aerodynamic cutoff diameter for the capture of road dust by a standard high-volume filtration sampler, based on a particle density of 2.0-2.5 g/cm^3. On this basis, road dust emissions of particles larger than 30-40 μm in diameter are not likely to be captured by high-volume samplers remote from unpaved roads. Furthermore, the potential drift distance of particles is governed by the initial injection height of the particle, the particle's terminal settling velocity, and the degree of atmospheric turbulence. Theoretical drift distances, as a function of particle diameter and mean wind speed, have been computed for unpaved road emissions.[1] These results indicate that, for a typical mean wind speed of 10 mi/hr (16 km/hr), particles larger than about 100 μm are likely to settle out within 20-30 feet (6-9 m) from the edge of the road. Dust that settles within this distance is not included in equation 1. Particles that are 30-100 μm in diameter are likely to undergo impeded settling. These particles, depending upon the extent of atmospheric turbulence, are likely to settle within a few hundred feet from the road. Smaller particles, particularly those less than 10-15 μm in diameter, have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence. Thus, based on the presently available data, it appears appropriate to report only those particles smaller than 30 μm (60 percent of the emissions predicted by Equation 1) as emissions that may remain indefinitely suspended.

11.2.1.4 Control Methods. Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working of soil stabilization chemicals into the roadbed, watering, and traffic control regulations. Paving as a control technique is often not practical because of its high cost. Surface chemical treatments and watering can be accomplished with moderate to low costs, but frequent retreatments are required for such techniques to be effective. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions, but such regulations may be difficult to enforce. Table 11.2.1-1 shows



approximate control efficiencies achievable for each method. Watering, because of the frequency of treatments required, is generally not feasible for public roads and is effectively used only where watering equipment is readily available and roads are confined to a single site, such as a construction location.

Table 11.2.1-1 CONTROL METHODS FOR UNPAVED ROADS

Control method	Approximate control efficiency, %
Paving	85
Treating surface with penetrating chemicals	50
Working soil stabilizing chemicals into roadbed	50
Speed control[a]	
30 mi/hr	75
20 mi/hr	65
10 mi/hr	80

[a]Based on the assumption that "uncontrolled" speed is typically 40 mi/hr. Between 30-50 mi/hr emissions are linearly proportional to vehicle speed. Below 30 mi/hr, however, emissions appear to be proportional to the square of the vehicle speed.

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11.2.3 Agricultural Tilling

11.2.3.1 General — The two universal objectives of agricultural tilling are the creation of the desired soil structure to be used as the crop seedbed and the eradication of weeds. Plowing, the most common method of tillage, consists of some form of cutting loose, granulating, and inverting the soil and turning under the organic litter. Implements that loosen the soil and cut off the weeds but leave the surface trash in place, have recently become more popular for tilling in dryland farming areas.

During a tilling operation, dust particles from the loosening and pulverization of the soil are injected into the atmosphere as the soil is dropped to the surface. Dust emissions are greatest when the soil is dry and during final seedbed preparation.

11.2.3.2 Emissions and Correction Parameters — The quantity of dust emissions from agricultural tilling is proportional to the area of land tilled. In addition, emissions depend on the following correction parameters, which characterize the condition of a particular field being tilled: (1) surface soil texture, and (2) surface soil moisture content.

Dust emissions from agricultural tilling have been found to vary in direct proportion to the silt content (that is, particles between 2 μm and 50 μm in diameter—as defined by U.S. Department of Agriculture) of the surface soil (0-10 cm depth).[1] The soil silt content is commonly determined by the Bunyoucous hydrometer method.[2]

Field measurements indicate that dust emissions from agricultural tilling are inversely proportional to the square of the surface soil moisture (0-10 cm depth).[1] Thornthwaite's precipitation-evaporation (PE) index[3] is a useful approximate measure of average surface soil moisture. The PE index is determined from total annual rainfall and mean annual temperature; rainfall amounts must be corrected for irrigation.

Available test data indicate no substantial dependence of emissions on the type of tillage implement when operating at a typical speed (for example, 8-10 km/hr).[1]

11.2.3.3 Corrected Emission Factor — The quantity of dust emissions from agricultural tilling, per acre of land tilled, may be estimated (within ± 30 percent) using the following empirical expression[1]:

$$E = \frac{1.4s}{\left(\frac{PE}{50}\right)^2} \qquad (3)$$

where: E = Emission factor, pounds per acre

s = Silt content of surface soil, percent

PE = Thornthwaite's precipitation-evaporation index (Figure 11.2.3-1)

Equation 3, which was derived from field measurements, excludes dust that settles out within 30-30 ft (6-9 m) of the tillage path.

On the average, the dust emissions from agricultural tilling, as given by Equation 3, have the following particle size characteristics[1]:

Particle size	*Weight percent*
$\leq$ 30 μm	80
$>$ 30 μm	20

The 30 μm value was determined[1] to be the effective aerodynamic cutoff diameter for capture of tillage dust by a standard high-volume filtration sampler, based on a particle density of 2.0-2.5 g/cm^3. As discussed in section 11.2.1.3, only particles smaller than about 30 μm have the potential for long range transport. Thus, for agricultural tilling about 80 percent of the emissions predicted by Equation 3 are likely to remain suspended indefinitely.

11.2.3.4 Control Methods[4] — In general, control methods are not applied to reduce emissions from agricultural tilling. Irrigation of fields prior to plowing will reduce emissions, but in many cases this practice would make the soil unworkable and adversely affect the plowed soil's characteristics. Control methods for agricultural activities are aimed primarily at reduction of emissions from wind erosion through such practices as continuous cropping, stubble mulching, strip cropping, applying limited irrigation to fallow fields, building windbreaks, and using chemical stabilizers. No data are available to indicate the effects of these or other control methods on agricultural tilling, but as a practical matter it may be assumed that emission reductions are not significant.

References for Section 11.2.3

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze. Development of Emission Factors for Fugitive Dust Sources. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0619. Publication No. EPA-450/3-74-037. June 1974.

3. Bouyoucos, G. J. Recalibration of the Hydrometer Method for Making Mechanical Analyses of Soils. Agron. J. *43*: 434-438, 1951.

5. Thornthwaite, C. W. Climates of North America According to a New Classification. Geograph. Rev. *21*: 633-655, 1931.

4. Jutze, G. A., K. Axetell, Jr., and W. Parker. Investigation of Fugitive Dust Sources Emissions and Control. PEDCo Environmental Specialists, Inc., Cincinnati, Ohio. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0044. Publication No. EPA-450/3-74-036a. June 1974.

Figure 11.2.2. Map of Tennessee's 3-hexagon grid system (hexagons are 1600 square miles in area)

11.2.3 Aggregate Storage Piles

11.2.3.1 General — An inherent part of the operation of plants that utilize minerals in aggregate form is the maintenance of outdoor storage piles. Storage piles are usually left uncovered, partially because of the necessity for frequent transfer of material into or out of storage.

Dust emissions occur at several points in the storage cycle: during loading of material onto the pile, during disturbances by strong wind currents, and during loadout of material from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust emissions.

11.2.3.2 Emissions and Correction Parameters — The quantity of dust emissions from aggregate storage operations varies linearly with the volume of aggregate passing through the storage cycle. In addition, emissions depend on the following correction parameters that characterize the condition of a particular storage pile: (1) age of the pile, (2) moisture content, and (3) proportion of aggregate fines.

When freshly processed aggregate is loaded onto a storage pile, its potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents resulting from aggregate transfer or high winds. As the aggregate weathers, however, the potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and the drying process is very slow.

11.2.3.3 Corrected Emission Factor — Total dust emissions from aggregate storage piles can be divided into the contributions of several distinct source activities that occur within the storage cycle:

1. Loading of aggregate onto storage piles.
2. Equipment traffic in storage area.
3. Wind erosion.
4. Loadout of aggregate for shipment.

Table 11.2.3-1 shows the emissions contribution of each source activity, based on field tests of suspended dust emissions from crushed stone and sand and gravel storage piles.[1] A 3-month storage cycle was assumed in the calculations.

Table 11.2.3-1 AGGREGATE STORAGE EMISSIONS

Source activity	Correction parameter	Approximate percentage of total
Loading onto piles	PE index[a]	12
Vehicular traffic	Rainfall frequency	40
Wind erosion	Climatic factor	33
Loadout from piles	PE index[a]	15
Total		100

[a] Thornthwaite's precipitation evaporation index.

Also shown in Table 11.2.3-1 are the climatic correction parameters that differentiate the emissions potential of one aggregate storage area from another. Overall, Thornthwaite's precipitation-evaporation index[3] best characterizes the variability of total emissions from aggregate storage piles.

The quantity of suspended dust emissions from aggregate storage piles, per ton of aggregate placed in storage, may be estimated using the following empirical expression[1]:

$$E = \frac{0.33}{\left(\frac{PE}{100}\right)^3} \qquad (3)$$

where: E = Emission factor, pounds per ton placed in storage

PE = Thornthwaite's precipitation-evaporation index (see Figure 11.2-2)

Equation 3 describes the emissions of particles less than 30 μm in diameter. This particle size was determined[1] to be the effective cutoff diameter for the capture of aggregate dust by a standard high-volume filtration sampler, based on a particle density of 2.0-2.5 g/cm^3. Because only particles smaller than 30 μm are included, equation 3 expresses the total emissions likely to remain indefinitely suspended. (See section 11.2.1.3).

11.2.3.4 Control Methods - Watering and use of chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicular traffic in the storage pile area. Frequent watering can, based on the breakdowns shown in Table 11.2-3, reduce total emission by about 40 percent. Watering of the storage piles themselves typically has only a very temporary, minimal effect on total emissions. A much more effective technique is to apply chemical wetting agents to provide better wetting of fines and longer retention of the moisture film. Continuous chemical treatment of material headed onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.[3]

References for Section 11.2.3

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze. Development of Emission Factors for Fugitive Dust Sources. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0619. Publication No. EPA-450/3-74-037. June 1974.

3. Thornthwaite, C. W. Climates of North America According to a New Classification. Geograph. Rev. 21: 633-655, 1931.

4. Jutze, G. A., K. Axetell, Jr., and W. Parker. Investigation of Fugitive Dust-Sources Emissions and Control. PEDCo Environmental Specialists, Inc., Cincinnati, Ohio. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0044. Publication No. EPA-450/3-74-036a. June 1974.

11.2.4 Heavy Construction Operations

11.2.4.1 General — Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are the prevalent construction categories with the highest emissions potential. Emissions during the construction of a building or road are associated with land clearing, blasting, ground excavation, cut and fill operations, and the construction of the particular facility itself. Dust emissions vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing weather. A large portion of the emissions result from equipment traffic over temporary roads at the construction site.

11.2.4.2 Emissions and Correction Parameters — The quantity of dust emissions from construction operations are proportional to the area of land being worked and the level of construction activity. Also, by analogy to the parameter dependence observed for other similar fugitive dust sources,[1] it is probable that emissions from heavy construction operations are directly proportional to the silt content of the soil (that is, particles smaller than 75 μm in diameter) and inversely proportional to the square of the soil moisture, as represented by Thornthwaite's precipitation-evaporation (P-E) index.[2]

11.2.4.3 Emission Factor — Based on field measurements of suspended dust emissions from apartment and shopping center construction projects, an approximate emission factor for construction operations is:

1.2 tons per acre of construction per month of activity

This value applies to construction operations with: (1) medium activity level, (2) moderate silt content (~50 percent), and (3) semiarid climate (PE ~50; see Figure 11.2.3-1). Test data are not sufficient to derive the specific dependence of dust emissions on correction parameters.

The above emission factor applies to particles less than about 30 μm in diameter, which is the effective cut-off size for the capture of construction dust by a standard high-volume filtration sampler[3], based on a particle density of 2.0-2.5 g/cm^3.

11.2.4.4 Control Methods — Watering is most often selected as a control method because water and necessary equipment are usually available at construction sites. The effectiveness of watering for control depends greatly on the frequency of application. An effective watering program (that is, twice daily watering with complete coverage) is estimated to reduce dust emissions by up to 50 percent.[3] Chemical stabilization is not effective in reducing the large portion of construction emissions caused by equipment traffic or active excavation and cut and fill operations. Chemical stabilizers are useful primarily for application on completed cuts and fills at the construction site. Wind erosion emissions from inactive portions of the construction site can be reduced by about 80 percent in this manner, but this represents a fairly minor reduction in total emissions compared with emissions occurring during a period of high activity.

References for Section 11.2.4

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze. Development of Emissions Factors for Fugitive Dust Sources. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0619. Publication No. EPA-450/3-74-037. June 1974.

2. Thornthwaite, C. W. Climates of North America According to a New Classification. Geograph. Rev. 21: 633-655, 1931.

3. Jutze, G. A., K. Axetell, Jr., and W. Parker. Investigation of Fugitive Dust-Sources Emissions and Control, PEDCo Environmental Specialists, Inc., Cincinnati, Ohio. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0044. Publication No. EPA-450/3-74-036a. June 1974.

APPENDIX A

MISCELLANEOUS DATA

Note: Previous editions of *Compilation of Air Pollutant Emission Factors* presented a table entitled Percentage Distribution by Size of Particles from Selected Sources without Control Equipment. Many of the data have become obsolete with the development of new information. As soon as the new information is sufficiently refined, a new table, complete with references, will be published for addition to this document.

Table A-1. NATIONWIDE EMISSIONS FOR 1977 [a]

[illegible]	Stationary combustion		Solid waste disposal		Mobile combustion		Industrial processes		Miscellaneous		Total[b]	
[illegible]	[illegible]	[illegible][c]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[a] Reference 1.

[b] Some totals may be rounded to a convenient number of figures.

[c] NA - Negligible.

Table A-2. DISTRIBUTION BY PARTICLE SIZE OF AVERAGE COLLECTION EFFICIENCIES FOR VARIOUS PARTICULATE CONTROL EQUIPMENT[a,b]

Type of collector	Efficiency, % Particle size range, μm					
	Overall	0 to 5	5 to 10	10 to 20	20 to 44	>44
Baffled settling chamber	58.6	7.5	22	43	80	90
Simple cyclone	65.3	12	33	57	82	91
Long cone cyclone	84.2	40	79	92	95	97
Multiple cyclone (12 in. diameter)	74.2	25	64	74	95	95
Multiple cyclone (6 in. diameter)	93.8	83	95	98	99.5	100
Irrigated long cone cyclone	91.0	63	93	96	98.5	100
Electrostatic precipitator	97.0	72	94.5	97	99.5	100
Irrigated electrostatic precipitator	99.0	97	99	99.5	100	100
Spray tower	94.5	90	96	98	100	100
Self induced spray scrubber	93.6	85	96	98	100	100
Disintegrator scrubber	98.5	93	98	99	100	100
Venturi scrubber	99.5	99	99.5	100	100	100
Wet impingement scrubber	97.9	96	98.5	99	100	100
Baghouse	99.7	99.5	100	100	100	100

[a]References 2 and 3.
[b]Data based on standard silica dust with the following particle size and weight distribution:

Particle size range, μm	Percent by weight
0 to 5	20
5 to 10	10
10 to 20	15
20 to 44	20
>44	35

Table A-3. THERMAL EQUIVALENTS FOR VARIOUS FUELS

Type of fuel	Btu (gross)	kcal
Solid fuels		
Bituminous coal	(21.0 to 28.0) x 10^6/ton	(5.8 to 7.8) x 10^6/MT
Anthracite coal	25.3 x 10^6/ton	7.03 x 10^6/MT
Lignite	16.0 x 10^6/ton	4.45 x 10^6/MT
Wood	21.0 x 10^6/cord	1.47 x 10^6/m^3
Liquid fuels		
Residual fuel oil	6.3 x 10^6/bbl	10 x 10^3/liter
Distillate fuel oil	5.8 x 10^6/bbl	9.35 x 10^3/liter
Gaseous fuels		
Natural gas	1,050/ft^3	9,350/m^3
Liquefied petroleum gas		
Butane	97,400/gal	6,480/liter
Propane	80,500/gal	6,030/liter

Table A-4. WEIGHTS OF SELECTED SUBSTANCES

Type of substance	lb/gal	g/liter
Asphalt	8.57	1030
Butane, liquid at 60° F	4.84	579
Crude oil	7.08	850
Distillate oil	7.05	845
Gasoline	6.17	739
Propane, liquid at 60° F	4.24	507
Residual oil	7.88	944
Water	8.4	1000

Table A-5. GENERAL CONVERSION FACTORS

Type of substance	Conversion factors
Fuel	
Oil	1 bbl = 42 gal = 159 liters
Natural gas	1 therm = 100,000 Btu = 95 ft^3
	1 therm = 25,000 kcal = 2.7 m^3
Agricultural products	
Corn	1 bu = 56 lb = 25.4 kg
Milo	1 bu = 60 lb = 25.4 kg
Oats	1 bu = 32 lb = 14.5 kg
Barley	1 bu = 48 lb = 21.8 kg
Wheat	1 bu = 60 lb = 27.2 kg
Cotton	1 bale = 500 lb = 226 kg
Mineral products	
Brick	1 brick = 6.5 lb = 2.95 kg
Cement	1 bbl = 375 lb = 170 kg
Cement	1 yd^3 = 2600 lb = 1180 kg
Concrete	1 yd^3 = 4000 lb = 1820 kg
Mobile sources	
Gasoline powered motor vehicle	1.0 mi/gal = 0.426 km/liter
Diesel powered motor vehicle	1.0 mi/gal = 0.426 km/liter
Steamship	1.0 gal/naut mi = 2.05 liters/km
Motorship	1.0 gal/naut mi = 2.05 liters/km
Other substances	
Paint	1 gal = 10 to 15 lb = 4.5 to 6.82 kg
Varnish	1 gal = 7 lb = 3.18 kg
Whiskey	1 bbl = 50 gal = 188 liters
Water	1 gal = 8.3 lb = 3.81 kg
Miscellaneous factors	1 lb = 7000 grains = 453.6 grams
	1 ft^3 = 7.48 gal = 28.32 liters
Metric system	1 ft = 0.3048 m
	1 mi = 1609 m
	1 lb = 453.6 g
	1 ton (short) = 907.2 kg
	1 ton (short) = 0.9072 Mt (metric ton)

REFERENCES FOR APPENDIX

1. Unpublished data file of nationwide emissions for 1970. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C.

2. Stairmand, C.J. The Design and Performance of Modern Gas Cleaning Equipment. J. Inst. Fuel. 29:58-80. 1956.

3. Stairmand, C.J. Removal of Grit, Dust, and Fume from Exhaust Gases from Chemical Engineering Processes. London Chem. Eng. p. 310-326. December 1965.

APPENDIX B
EMISSION FACTORS
AND
NEW SOURCE PERFORMANCE STANDARDS
FOR STATIONARY SOURCES

The New Source Performance Standards (NSPS) promulgated by the Environmental Protection Agency for various industrial categories and the page reference in this publication where uncontrolled emission factors for those sources are discussed are presented in Tables B-1 and B-2. Note that, in the case of steam-electric power plants, the NSPS encompass much broader source categories than the corresponding emission factors. In several instances, the NSPS were formulated on different bases than the emission factors (for example, grains per standard cubic foot versus pounds per ton). Finally, note that NSPS relating to opacity have been omitted because they cannot (at this time) be directly correlated with emission factors.

Table 8.1. PROMULGATED NEW SOURCE PERFORMANCE STANDARDS – GROUP I SOURCES[a]

Source category and pollutant	New Source Performance Standard (maximum 2-hr average)	AP-42 page reference
Fossil-fuel fired steam generators with > 63 x 10^6 kcal/hr (250 x 10^6 Btu/hr) of heat input		
Coal burning plants (excluding lignite)		
Pulverized wet bottom		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1.3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1.3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1.3
Pulverized dry bottom		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1.3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1.3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1.3
Pulverized cyclone		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1.3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1.3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1.3
Spreader stoker		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.1.3
Sulfur dioxide	2.2 g/10^6 cal heat input (1.2 lb/10^6 Btu)	1.1.3
Nitrogen oxides (as NO_2)	1.26 g/10^6 cal heat input (0.70 lb/10^6 Btu)	1.1.3
Residual oil burning plants		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.3.2
Sulfur dioxide	1.4 g/10^6 cal heat input (0.80 lb/10^6 Btu)	1.3.2
Nitrogen oxides (as NO_2)	0.54 g/10^6 cal heat input (0.30 lb/10^6 Btu)	1.3.2
Natural gas burning plants		
Particulates	0.18 g/10^6 cal heat input (0.10 lb/10^6 Btu)	1.4.2
Nitrogen oxides (as NO_2)	0.36 g/10^6 cal heat input (0.20 lb/10^6 Btu)	1.4.2
Municipal incinerators		
Particulates	0.18 g/Nm^3 (0.08 gr/scf) corrected to 12% CO_2	2.1.1
Portland cement plants		
Kiln – dry process		
Particulates	0.15 kg/MT (0.30 lb/ton) of feed to kiln	8.6.3

Table B-1. (continued). PROMULGATED NEW SOURCE PERFORMANCE STANDARDS – GROUP 1 SOURCES[a]

Source category and pollutant	New Source Performance Standard (maximum 2 hr average)	AP-42 page reference
Kiln – wet process Particulates	0.15 kg/MT (0.30 lb/ton) of feed to kiln	8.6.3
Clinker cooler Particulates	0.050 kg/MT (0.10 lb/ton) of feed to kiln	8.6.4
Nitric acid plants Nitrogen oxides (as NO_2)	1.5 kg/MT (3.0 lb/ton) of 100% acid produced	8.8.4
Sulfuric acid plants Sulfur dioxide	2.0 kg/MT (4.0 lb/ton) of 100% acid produced	8.17.6
Sulfuric acid mist (as H_2SO_4)	0.075 kg/MT (0.15 lb/ton) of 100% acid produced	8.17.7

[a]Title 40 – Protection of Environment, Part 60 – Standards of Performance for New Stationary Sources. Federal Register, 36 (247):24876. December 23, 1971.

Table B-2. PROMULGATED NEW SOURCE PERFORMANCE STANDARDS
—GROUP II SOURCES[a]

Source category and pollutant	New Source Performance Standard	AP-42 page reference
Asphalt concrete plants		
Particulates	90 mg/Nm³ (0.040 gr/dscf)	8.1.4
Petroleum refineries: Fluid catalytic cracking units		
Particulates	80 mg/Nm³ (0.035 gr/dscf)[b]	9.1.3
Carbon monoxide	0.050% by volume	9.1.3
Storage vessels for petroleum liquids		
"Floating roof" storage tanks		
Hydrocarbons	If true vapor pressure under storage conditions exceeds 78 mm (1.52 psia) mercury but is no greater than 570 mm (11.1 psia) mercury, the vessel must be equipped with a floating roof or its equivalent.	4.3.8
Secondary lead smelters		
Blast (cupola) furnaces		
Particulates	50 mg/Nm³ (0.022 gr/dscf)	7.11.2
Reverberatory furnaces		
Particulates	50 mg/Nm³ (0.022 gr/dscf)	7.11.2
Secondary brass and bronze ingot production plants		
Reverberatory furnaces		
Particulates	50 mg/Nm³ (0.022 gr/dscf)	7.9.2
Electric induction furnaces		
Particulates	50 mg/Nm³ (0.022 gr/dscf)	7.9.2
Blast furnaces		
Particulates	50 mg/Nm³ (0.022 gr/dscf)	7.9.2
Iron and steel plants		
Basic oxygen process furnaces		
Particulates	50 mg/Nm³ (0.022 gr/dscf)	7.5.5
Sewage treatment plants		
Sewage sludge incinerators		
Particulates	0.65 g/kg (1.30 lb/ton) of dry sludge input	2.5.2

[a] Title 40 - Protection of Environment, Part 60 - Standards of Performance for New Stationary Sources - Additions and Miscellaneous Amendments. Federal Register. 39 (47). March 8, 1974.

[b] The actual NSPS reads "1.0 kg/1000 kg (1.0 lb/1000 lb) of coke burn-off in the catalyst regenerator," which is approximately equivalent to an exhaust gas concentration of 80 mg/Nm³ (0.035 gr/dscf).

APPENDIX C
NEDS SOURCE CLASSIFICATION CODES
AND
EMISSION FACTOR LISTING

The Source Classification Codes (SCC's) presented herein comprise the basic "building blocks" upon which the National Emissions Data System (NEDS) is structured. Each SCC represents a process or function within a source category logically associated with a point of air pollution emissions. In NEDS, any operation that causes air pollution can be represented by one or more of these SCC's.

Also presented herein are emission factors for the five NEDS pollutants (particulates, sulfur oxides, nitrogen oxides, hydrocarbons, and carbon monoxide) that correspond to each SCC. These factors are utilized in NEDS to automatically compute estimates of air pollutant emissions associated with a process when a more accurate estimate is not supplied to the system. These factors are, for the most part, taken directly from AP-42. In certain cases, however, they may be derived from better information not yet incorporated into AP-42 or be based merely on the similarity of one process to another for which emissions information does exist.

Because these emission factors are merely single representative values taken, in many cases, from a broad range of possible values and because they do not reflect all of the variables affecting emissions that are described in detail in this document, the user is cautioned not to use the factors listed in Appendix C out of context to estimate the emissions from any given source. Instead, if emission factors must be used to estimate emissions, the appropriate section of this document should be consulted to obtain the most applicable factor for the source in question. The factors presented in Appendix C are reliable only when applied to numerous sources as they are in NEDS.

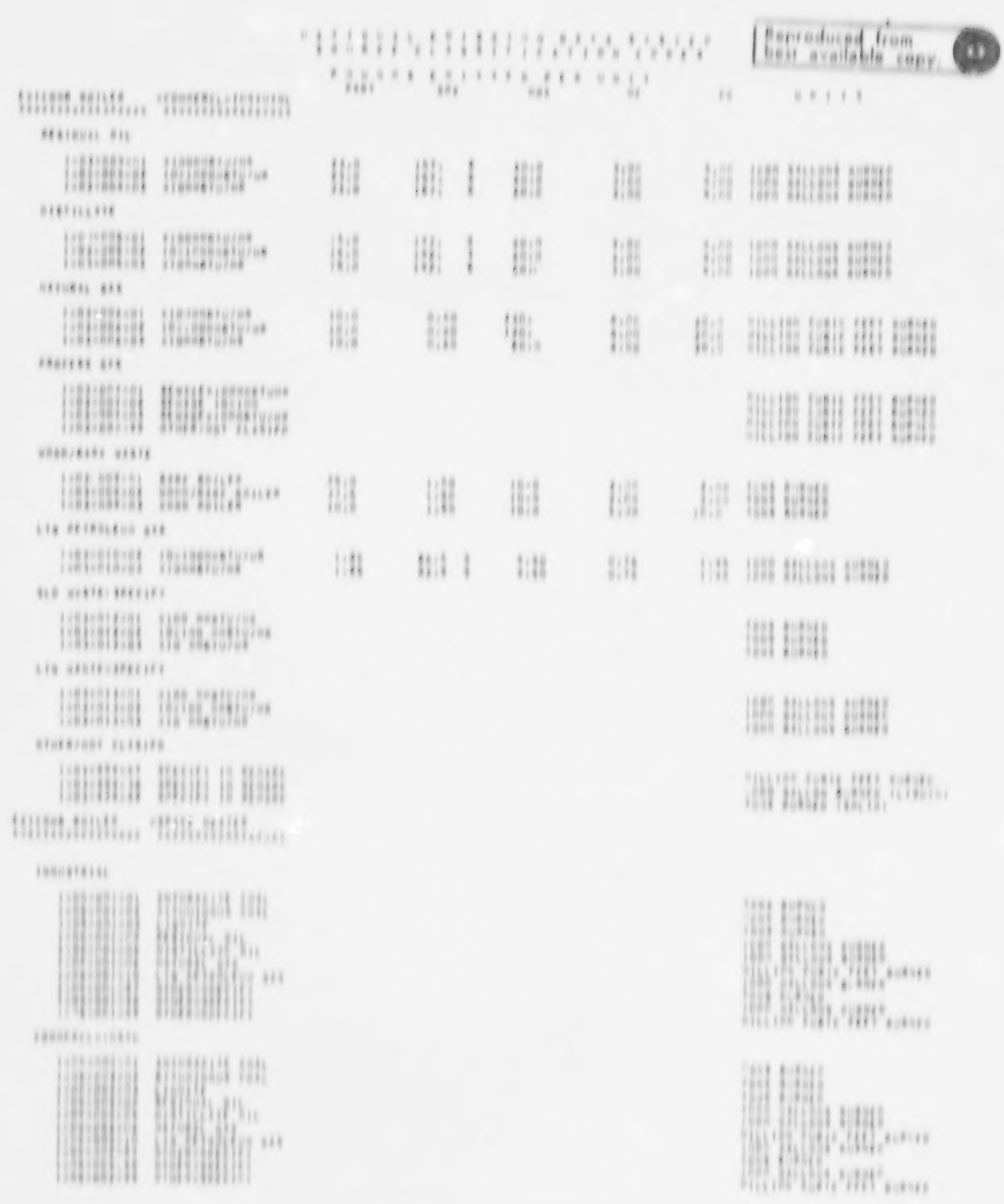
NOTE: The Source Classification Codes and emission factor listing presented in Appendix C was created on October 31, 1975, to replace the listing dated June 30, 1974. The listing has been updated to include several new Source Classification Codes as well as several new or revised emission factors that are considered necessary for the improvement of NEDS. The listing will be updated periodically as better source and emission factor information becomes available. Any comments regarding this listing, especially those pertaining to the need for additional SCC's, should be directed to:

Chief, Emission Factor Section (MD-14)
National Air Data Branch
Environmental Protection Agency
Research Triangle Park, N.C. 27711

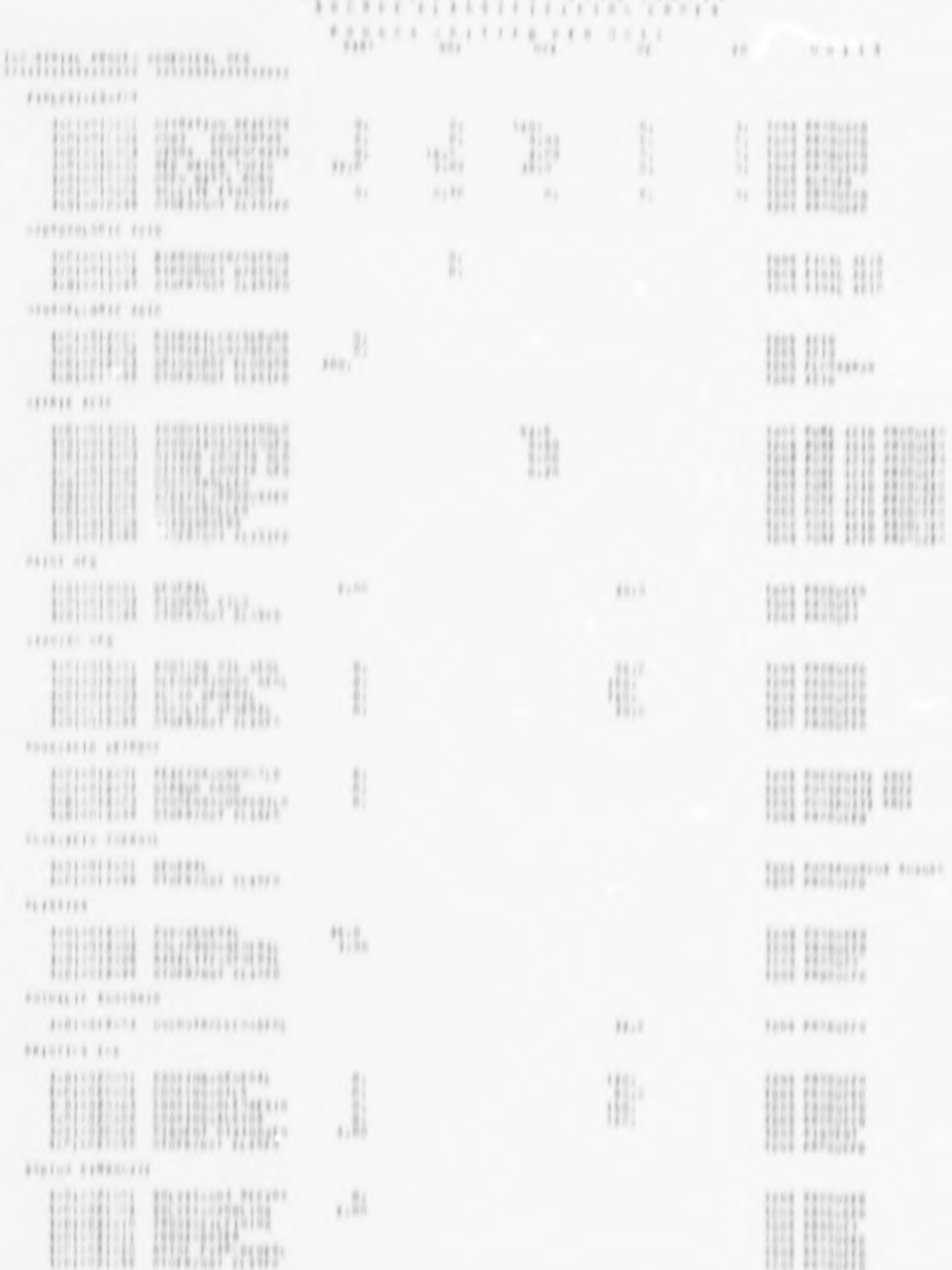
Reproduced from best available copy.

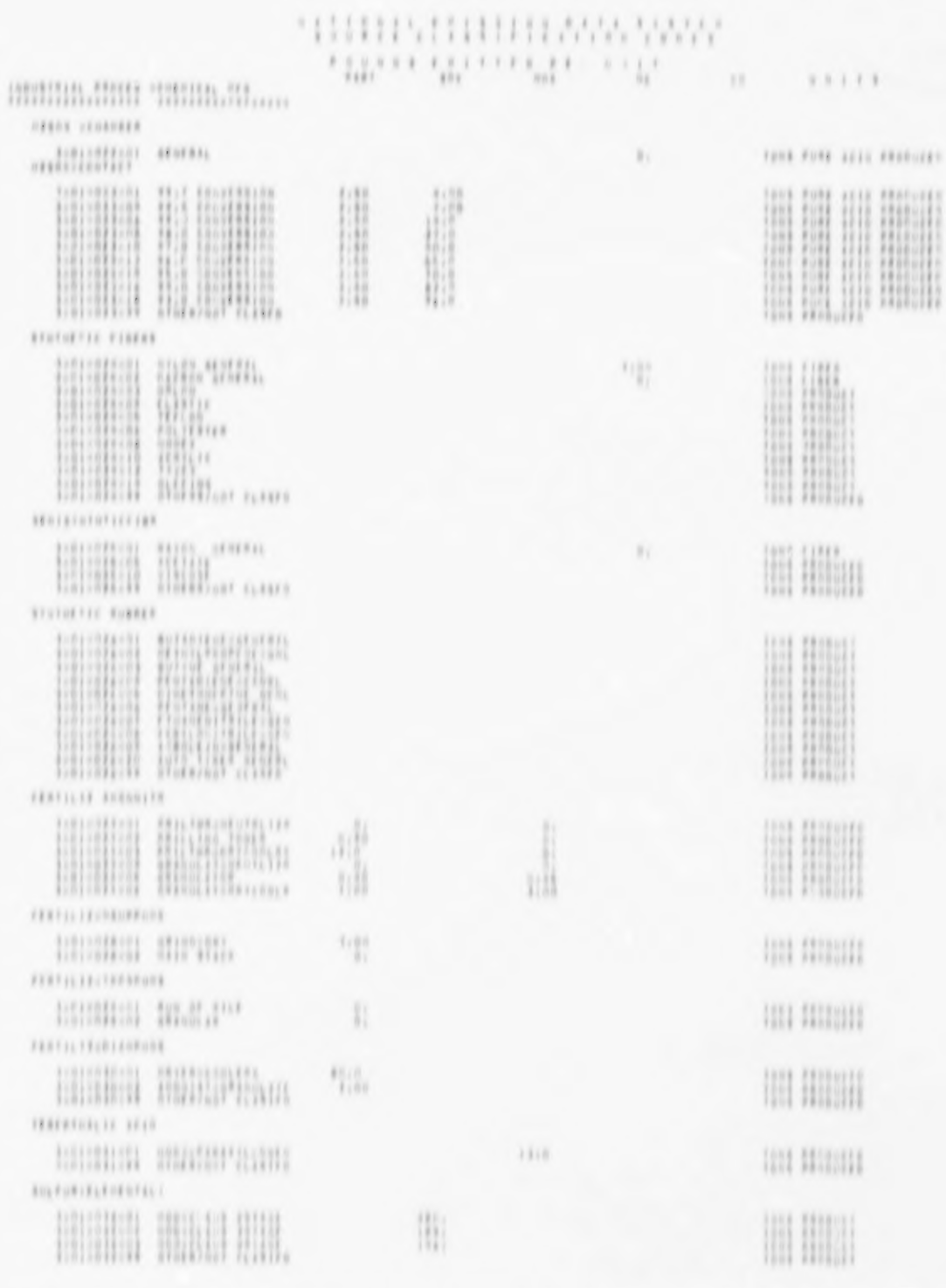
(a) Includes coal coke.

Reproduced from best available copy.



(a) INDICATES FUEL HAS ASH CONTENT; (b) INDICATES FUEL HAS A SULFUR CONTENT OF 0.5% BY WEIGHT OR LESS (AS DELIVERED).





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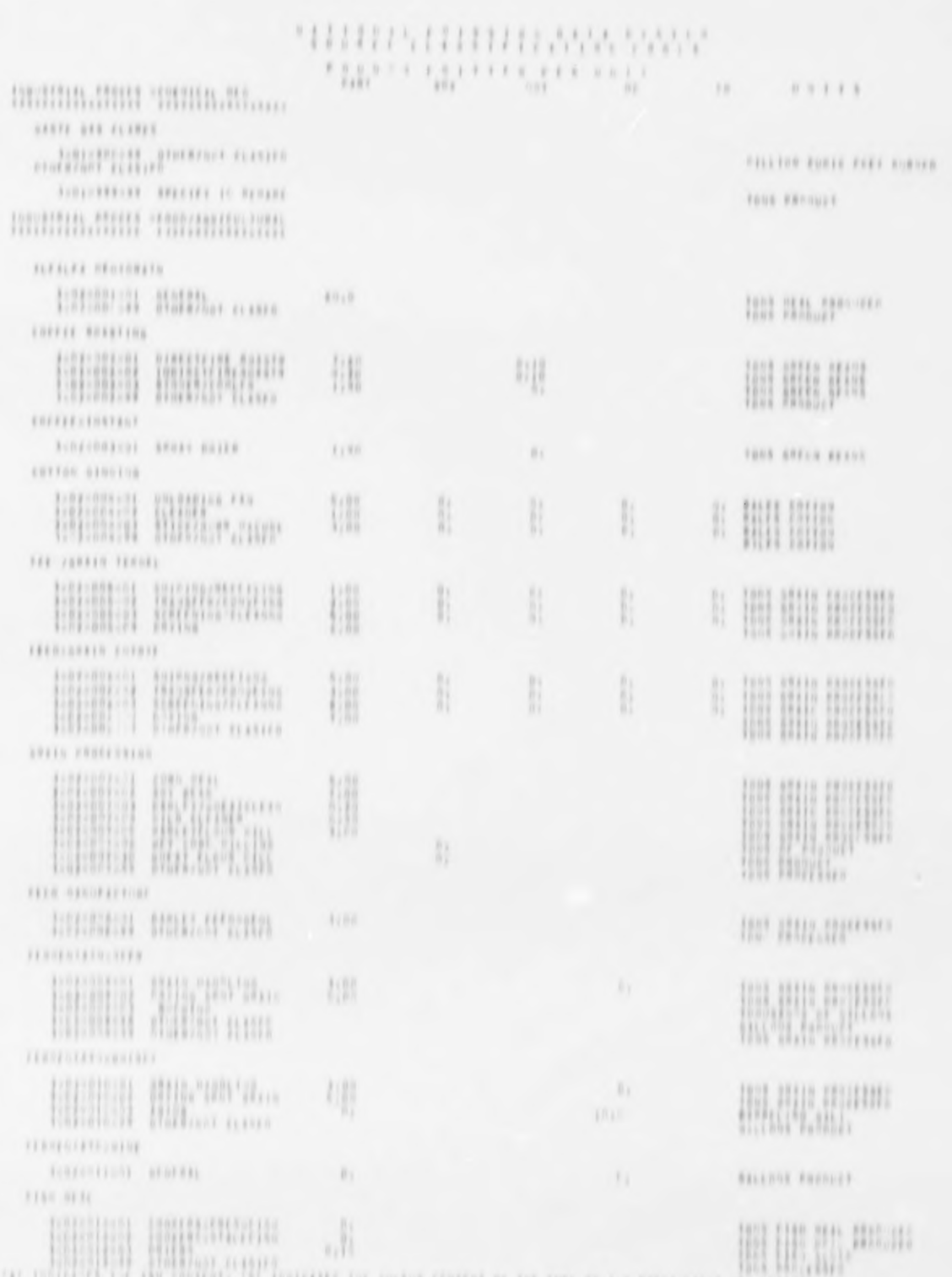

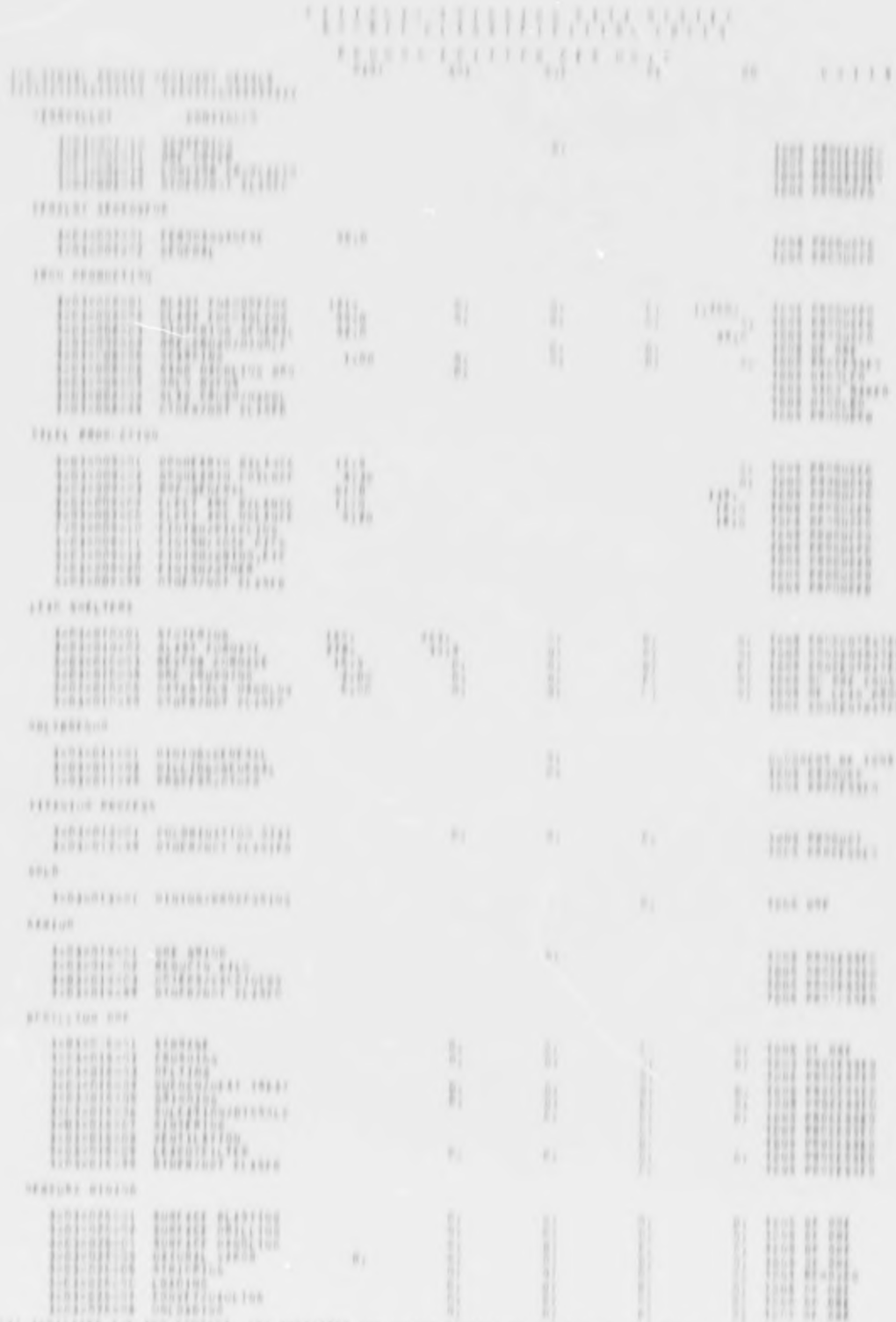

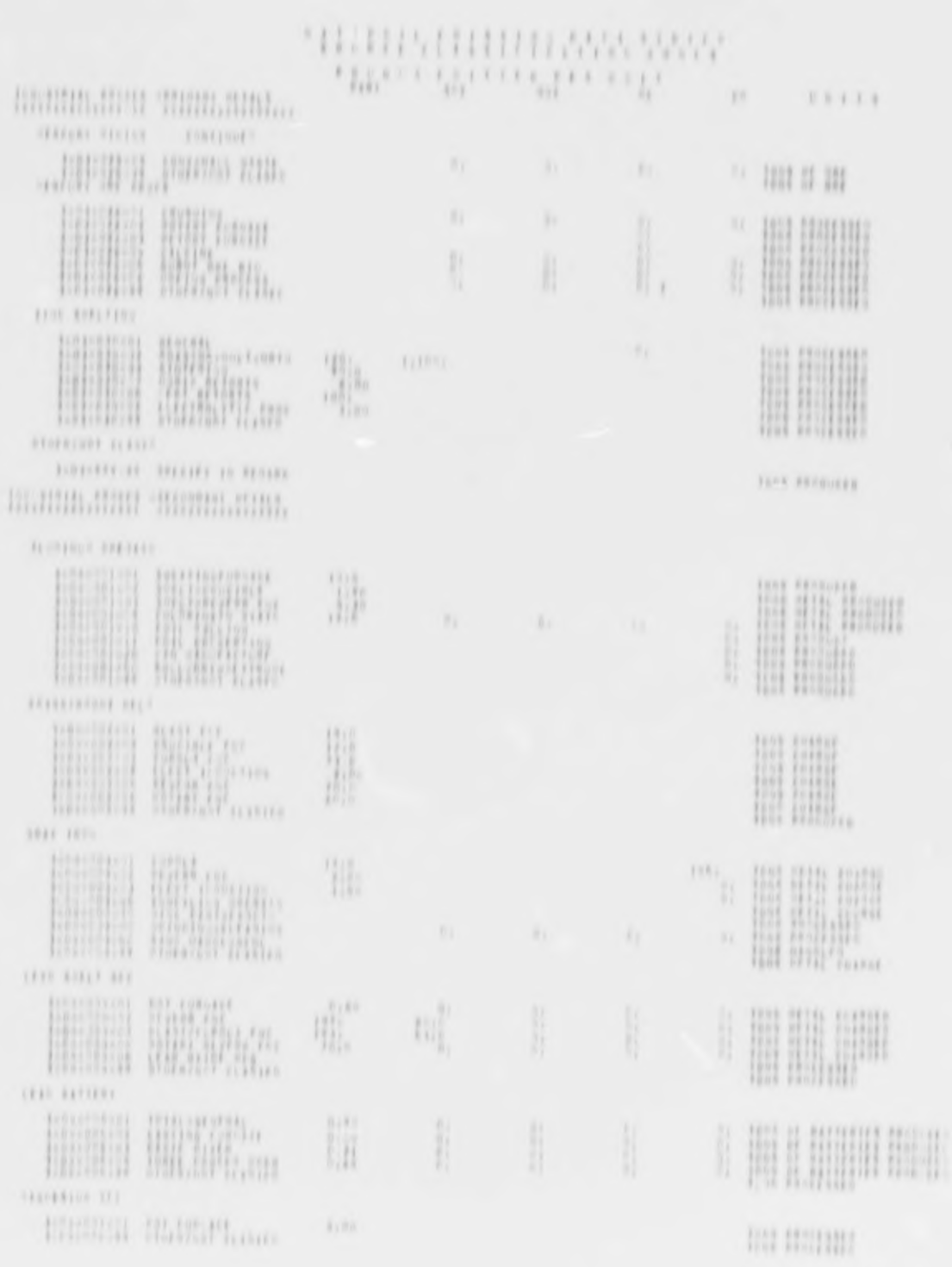

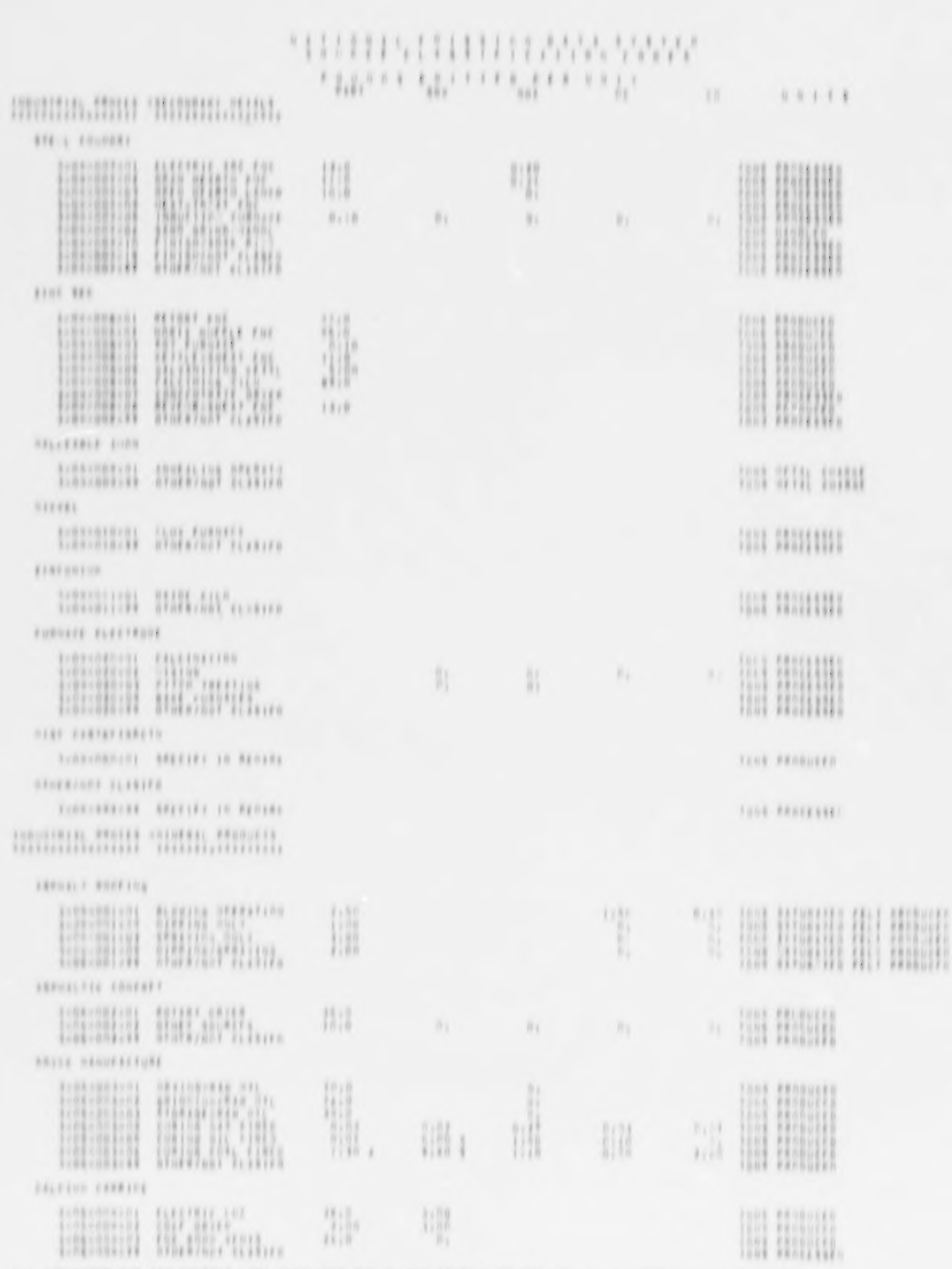

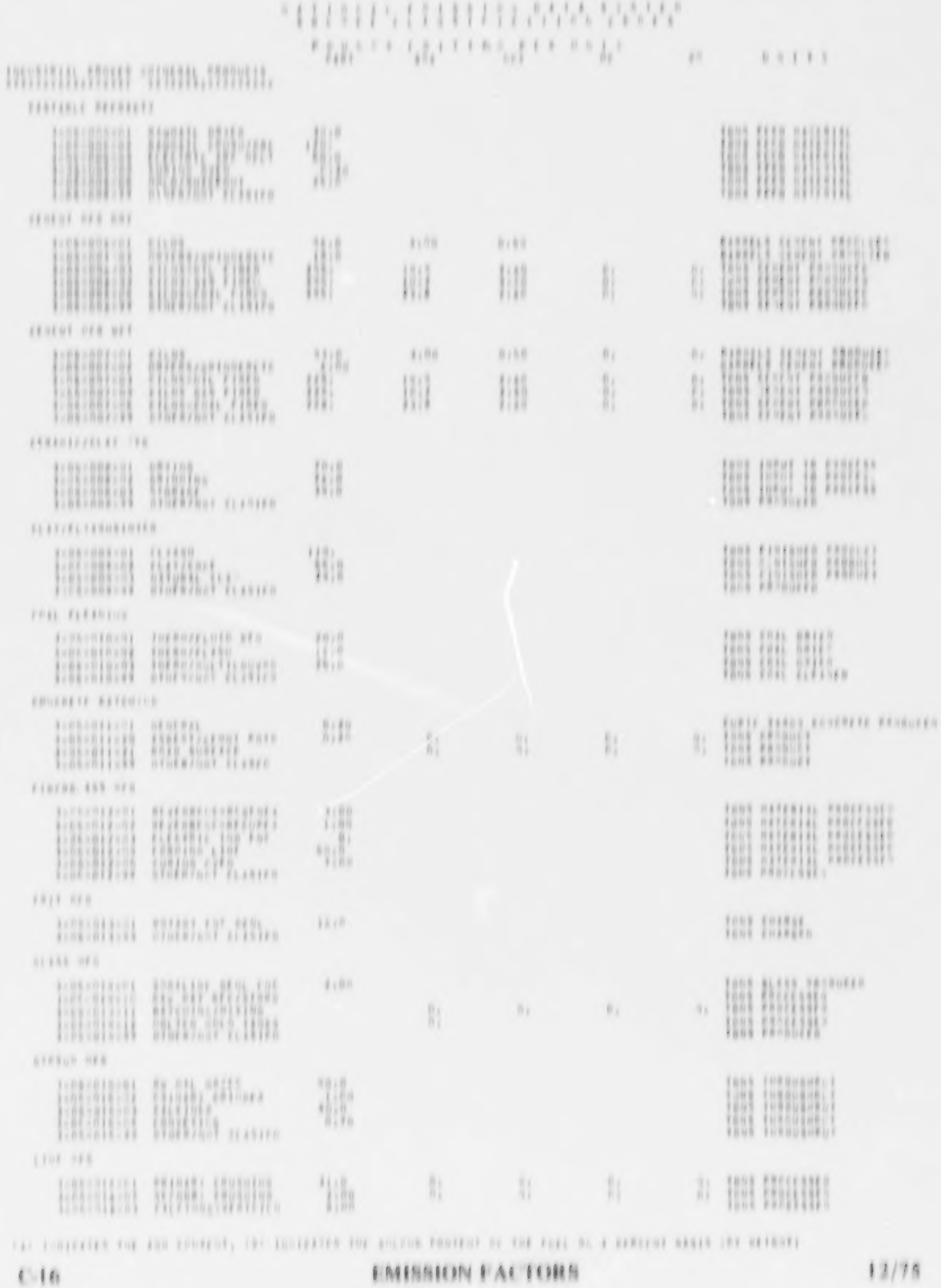

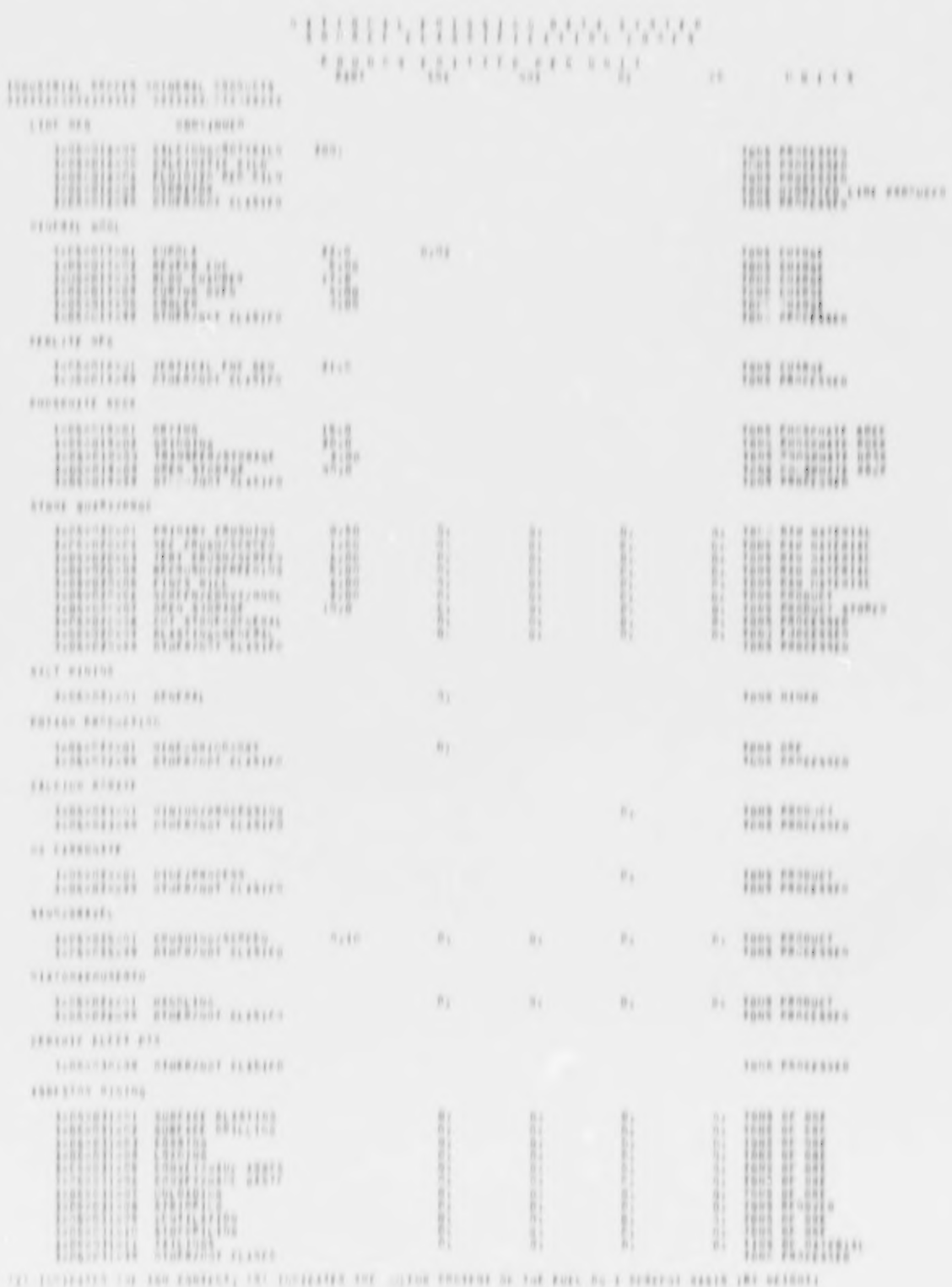

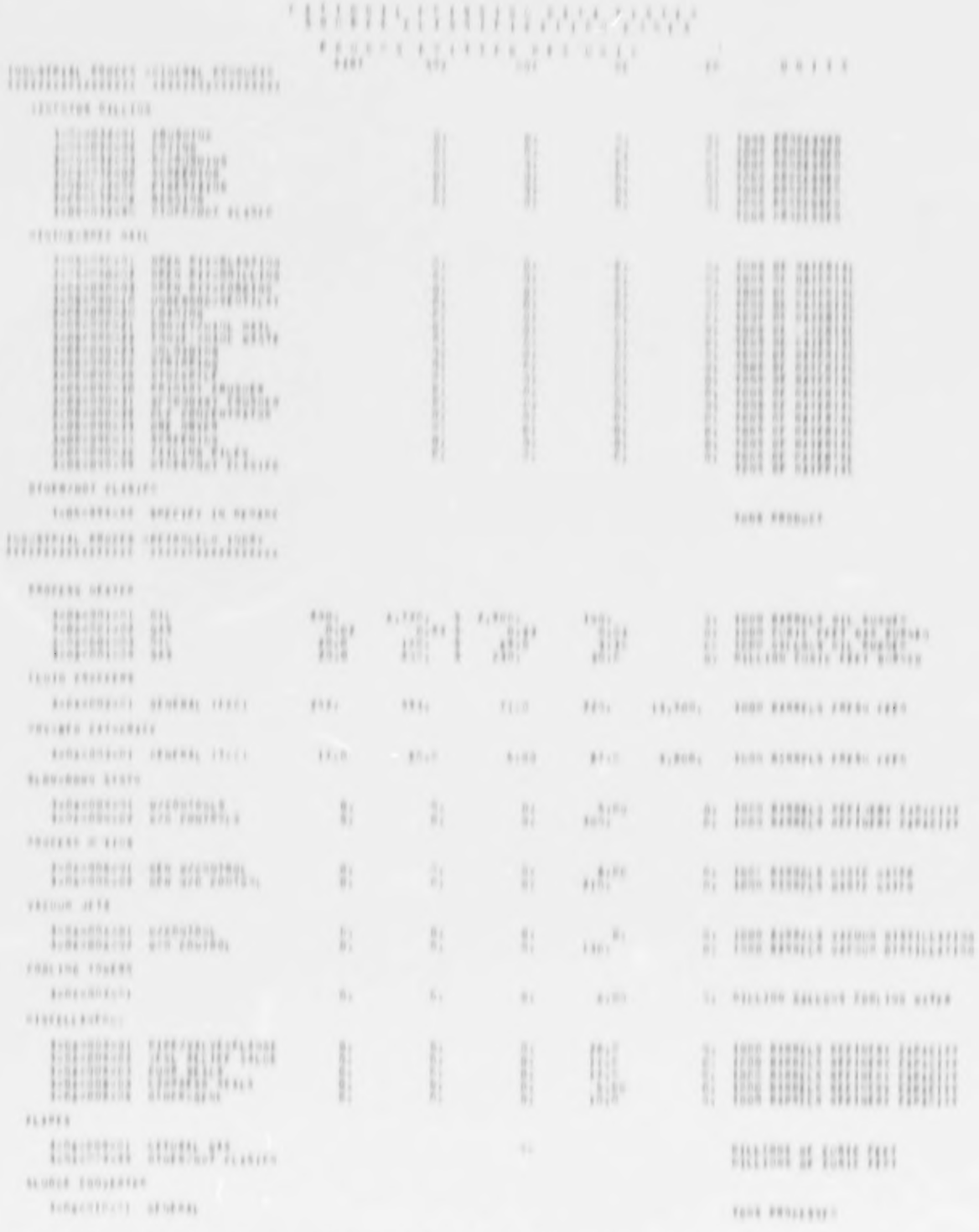

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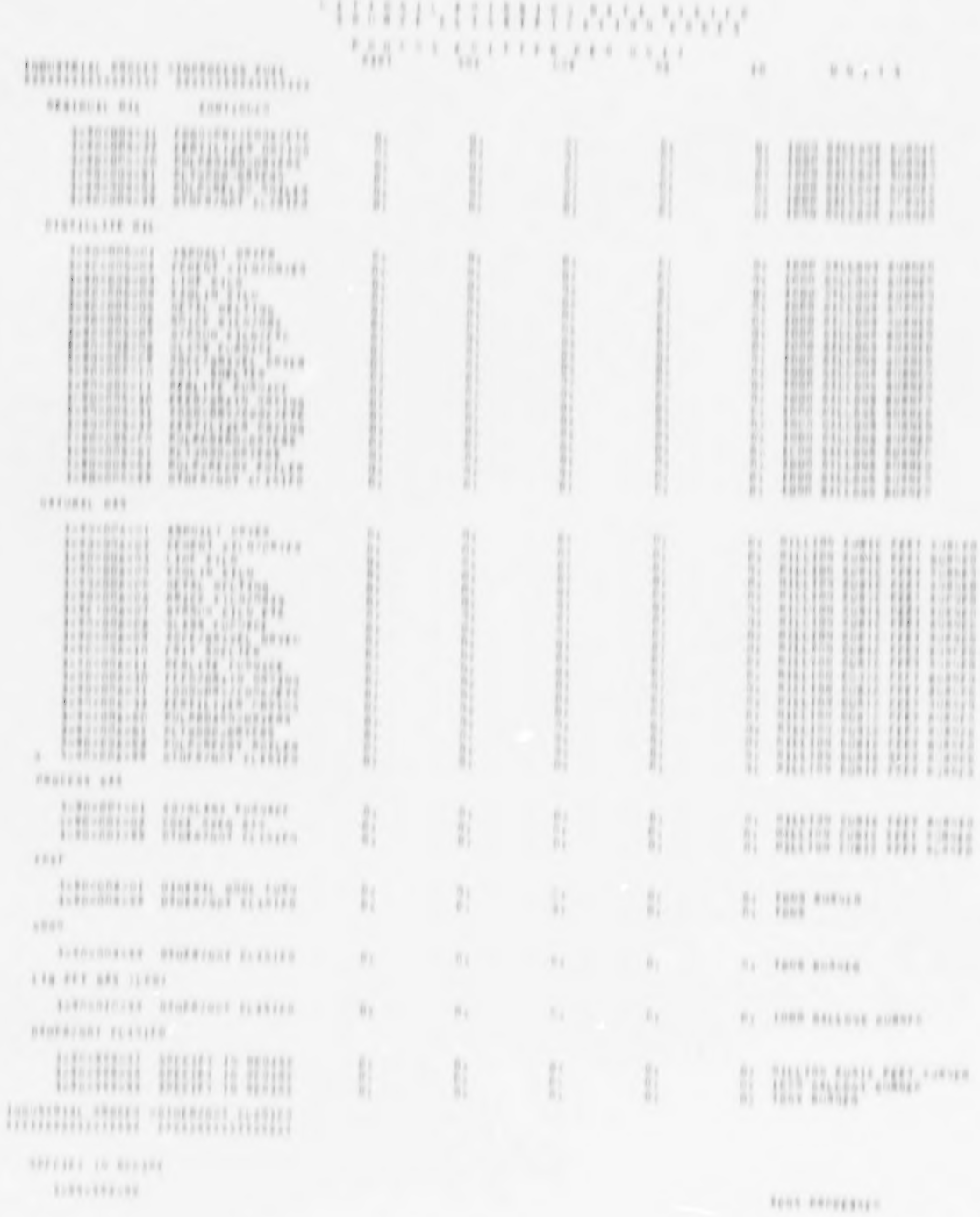
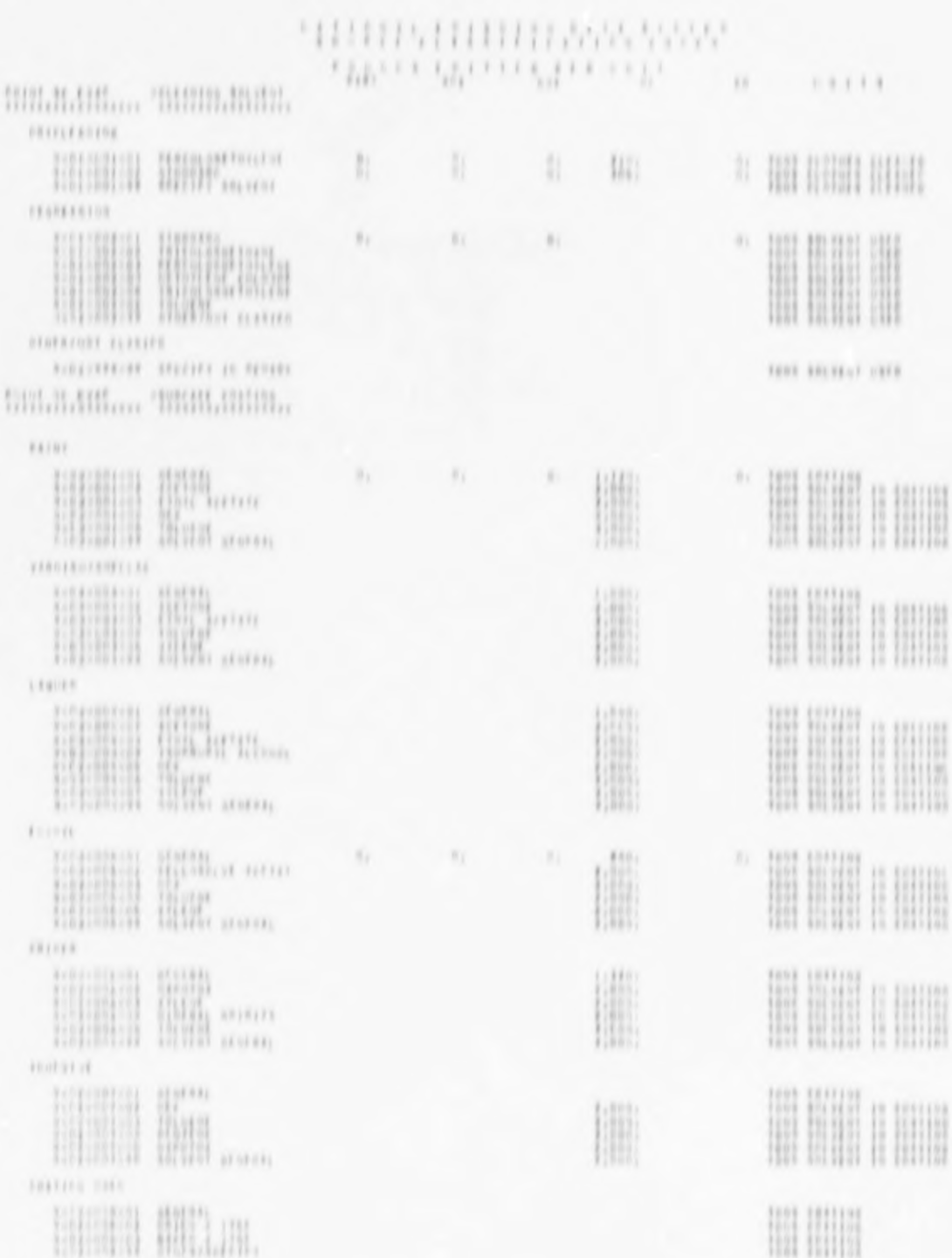
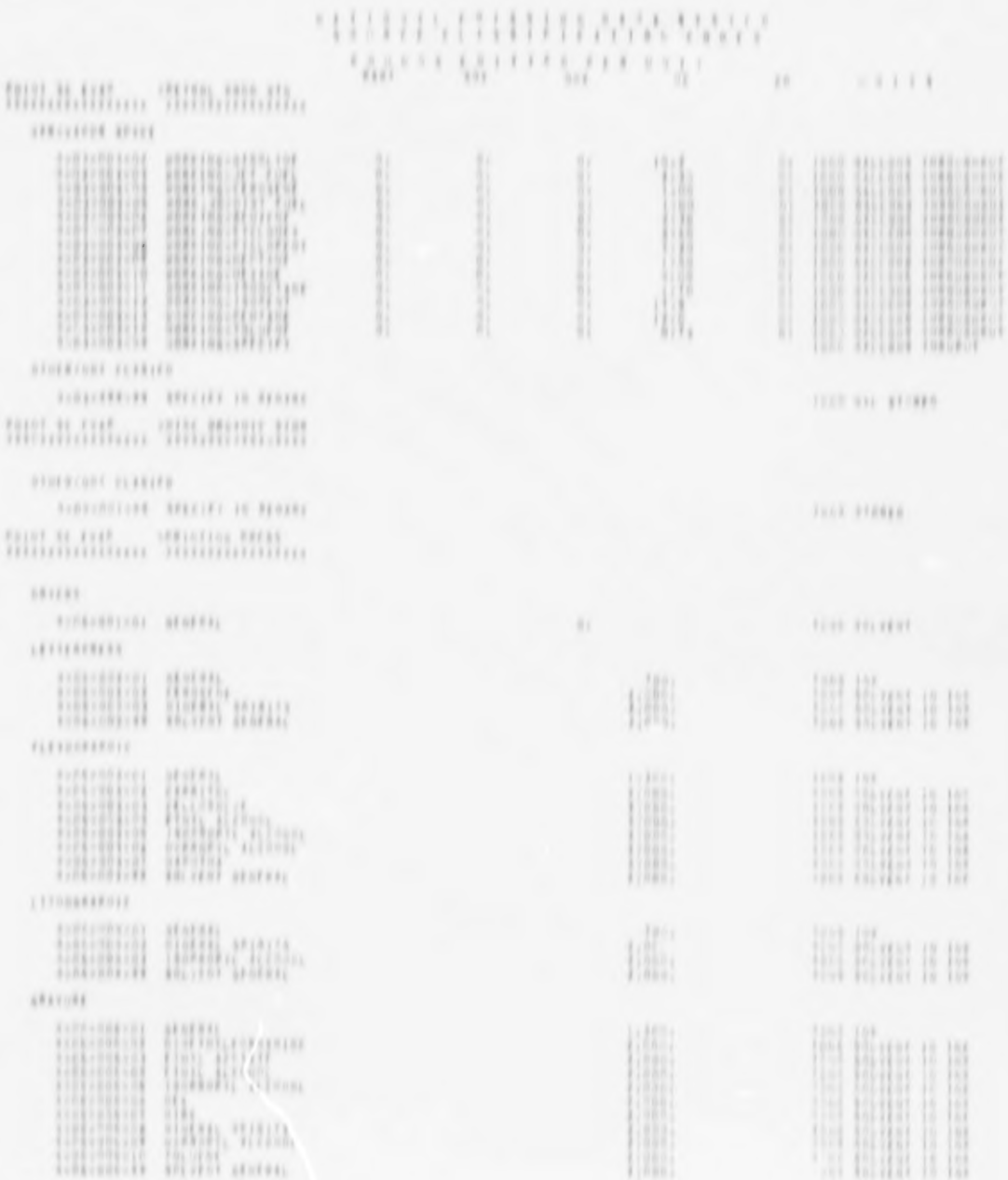
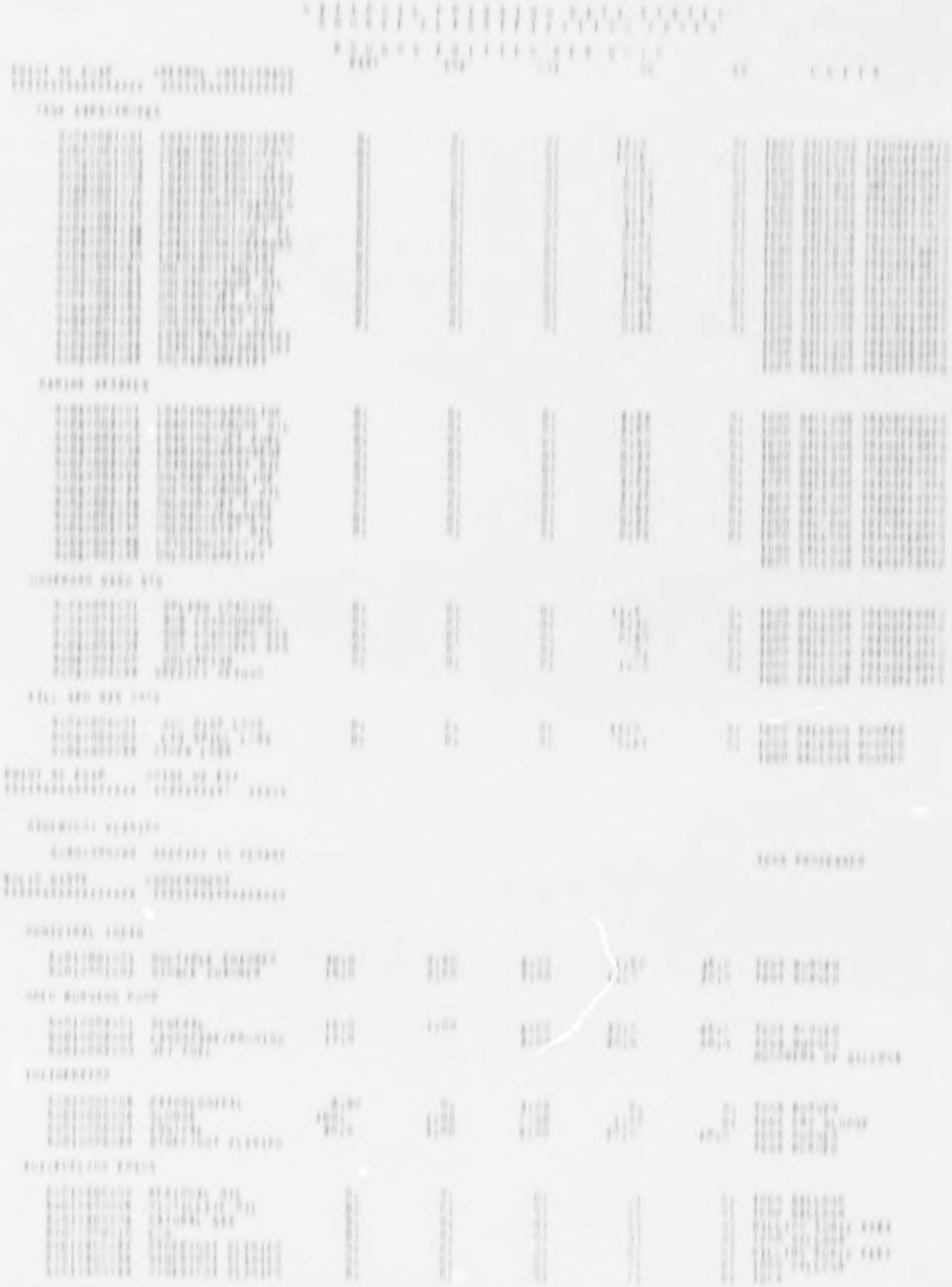




(a) Indicates the end content. (b) Indicates the plastic content of the soil by a standard sample (b) values.



[a] INDICATES USE AND CONTENT. [b] INDICATES USE SULFUR CONTENT OF THE FUEL ON A WEIGHT BASIS (BY WEIGHT).



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APPENDIX D
PROJECTED EMISSION FACTORS FOR HIGHWAY VEHICLES

prepared by
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Marcia E. Williams,
and Charles C. Masser

INTRODUCTION

In earlier editions of *Compilation of Air Pollutant Emission Factors* (AP-42), projected emission factors for highway vehicles were integrated with actual, measured emission factors. Measured emission factors are mean values arrived at through a testing program that involves a random statistical sample of in-use vehicles. Projected emission factors, on the other hand, are a conglomeration of measurements of emissions from prototype vehicles, best estimates based on applicable Federal standards, and, in some cases, outright educated guesses. In an attempt to make the user more aware of these differences, projected emission factors are separated from the main body of emission factors and presented as an appendix in this supplement to the report.

Measured emission estimates are updated annually at the conclusion of EPA's annual surveillance program. Projected emission factors, however, are updated when new data become available and not necessarily on a regular schedule. For several reasons, revisions to projected emission factors are likely to be necessary more frequently than on an annual basis. First, current legislation allows for limited time extensions for achieving the statutory motor vehicle emission standards. Second, Congressional action that would change the timetable for achieving these standards, the standards themselves, or both is likely in the future. Third, new data on catalyst-equipped (1975+) automobiles are becoming available daily. As a result, the user of these data is encouraged to keep abreast of happenings likely to affect the data presented herein. Every attempt will be made to revise these data in a timely fashion when revisions become necessary.

This appendix contains mostly tables of data. Emission factor calculations are only briefly described because the more detailed discussion in Chapter 3 applies in nearly all cases. Any exceptions to this are noted. The reader is frequently referred to the text of Chapter 3; thus, it is recommended that a copy be close at hand.

Six vehicle categories encompassing all registered motor vehicles in use and projected to be in use on U.S. highways are dealt with in this appendix. The categories in order of presentation are:

1. Light-duty, gasoline-powered vehicles
2. Light-duty, gasoline-powered trucks
3. Light-duty, diesel-powered vehicles
4. Heavy-duty, gasoline-powered vehicles
5. Heavy-duty, diesel-powered vehicles
6. Motorcycles
7. All highway vehicles

D.1 LIGHT DUTY, GASOLINE POWERED VEHICLES

D.1.1 General

This vehicle category represents passenger cars, a major source of ambient levels of carbon monoxide, hydrocarbons, and nitrogen oxides in many areas of the United States. The reader is encouraged to become familiar with section 3.1.2, which discusses light-duty gasoline-powered vehicles in greater detail, before using the data presented here.

D.1.2 CO, HC, NO_x Exhaust Emissions

The calculation of projected composite emission factors is limited in this presentation to the Federal Test Procedure (FTP) methodology (see section 3.1.2). The modal technique is not, generally, amenable to absolute emission projections. A user who wants to quantify the projected emissions over a specific driving sequence can apply the modal technique to the 1972 calendar as discussed in section 3.1.2. A ratio of the 1972 calendar year modal emissions to the 1972 calendar year FTP emissions can be obtained, and this ratio can be applied to a projected FTP value to adjust for the specific driving cycle of interest.

The calculation of composite emission factors for light duty vehicles using the FTP procedure is given by:

$$e_{apstws} = \sum_{i=1}^{n} e_{ipn}\, m_{in}\, c_{ips}\, c_{ipt}\, b_{ptws} \qquad \text{(D1-1)}$$

where: e_{apstws} = Composite emission factor in grams per mile (g/mile) (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (s)

e_{ipn} = The FTP mean emission factor for the i^{th} model year light-duty vehicles during calendar year (n) and for pollutant (p)

m_{in} = The fraction of annual travel by the i^{th} model year light-duty vehicles during calendar year (n)

c_{ips} = The speed correction factor for the i^{th} model year light-duty vehicles for pollutant (p), and average speed (s). This variable applies only to CO, HC, and NO_x

c_{ipt} = The temperature correction for the i^{th} model year light-duty vehicles for pollutant (p) and ambient temperature (t)

b_{ptws} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty vehicles for pollutant (p), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (s).

The variable e_{ipn} is summarized in Tables D.1-1 through D.1-21, segregated by location (California, non-California, high altitude). The input m_{in} is described by example in Table D.1-22. The speed correction factors are presented in Tables D.1-23 and D.1-24.

The temperature correction and hot/cold vehicle operation correction factors, given in Table D.1-24, are separated into non-catalyst and catalyst correction factors. Catalyst correction factors should be applied for model years 1975-1977. For non-catalyst vehicles, the factors are the same as those presented in section 3.1.2.

For catalyst vehicles, emissions during the hot start phase of operation (vehicle start-up after a short—less than 1 hour—engine-off period) are greater than vehicle emissions during the hot stabilized phase. Therefore, the correction factor is a function of the percentage of cold operation, the percentage of hot start operation, and the ambient temperature(1).

$$\text{fptw} = \frac{w + (100 - w)R(t)}{20 + 80\,R(t)} \qquad \begin{array}{l}\text{Pre-1975}\\ \text{model years}\end{array} \qquad \text{(EI-2)}$$

$$\text{fptws} = \frac{w + s\,R(t) + (100 - w - s)\,g(t)}{20 + 27\,R(t) + 53\,g(t)} \qquad \begin{array}{l}\text{Post-1974}\\ \text{model years}\end{array} \qquad \text{(EI-3)}$$

Table 0.1-1. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1973 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	84.0	58.4	8.8	5.5	3.34	2.07
1968	67.6	42.0	6.8	4.2	4.32	2.68
1969	65.4	40.6	6.3	3.3	5.08	3.16
1970	56.0	34.8	5.3	3.3	4.35	2.70
1971	53.5	33.2	4.3	2.7	4.30	2.67
1972	39.0	24.2	3.5	2.2	4.66	2.63
1973	37.0	23.0	3.2	2.0	3.1	1.9
High altitude						
Pre 1968	143	88.8	12.0	7.5	2.0	1.2
1968	106	65.8	7.6	4.7	2.80	1.77
1969	101	62.7	6.6	4.1	2.93	1.82
1970	91.0	56.5	6.0	3.7	3.32	2.06
1971	84.0	52.2	5.7	3.5	2.74	1.70
1972	84.0	52.2	5.2	3.2	3.08	1.91
1973	80.0	49.7	4.7	2.8	3.1	1.93

Table 0.1-2. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1973 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre 1968	84.0	58.4	8.8	5.5	3.34	2.07
1968	81.0	50.3	6.5	4.0	3.61	2.24
1967	81.0	50.3	6.5	4.0	3.61	2.24
1968	67.6	42.0	6.8	4.2	4.32	2.68
1969	65.4	40.6	5.3	3.3	5.08	3.16
1970	56.0	34.8	5.3	3.3	4.35	2.70
1971	53.5	33.2	4.3	2.7	3.83	2.38
1972	49.0	30.4	3.8	2.4	3.81	2.37
1973	37.0	23.0	3.2	2.0	3.1	1.9

Table D.1-3. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE-POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1974 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	95.0	59.0	6.9	5.5	3.34	2.07
1968	70.6	43.8	7.4	4.6	4.32	2.68
1969	68.4	42.5	5.8	3.6	5.08	3.15
1970	58.5	36.3	5.0	3.6	4.35	2.70
1971	56.0	34.8	4.7	2.9	4.30	2.67
1972	41.0	25.5	3.8	2.4	4.55	2.83
1973	39.0	24.2	3.5	2.2	3.3	2.0
1974	37.0	23.0	3.2	2.0	3.1	1.9
High altitude						
Pre 1968	145	90.0	12.1	7.5	2.0	1.2
1968	111	68.9	8.3	5.2	2.86	1.78
1969	106	65.8	7.2	4.5	2.93	1.82
1970	95.0	59.0	6.6	4.1	3.32	2.06
1971	88.0	54.6	6.2	3.9	2.74	1.70
1972	88.0	54.6	5.7	3.5	3.08	1.91
1973	84.0	52.2	5.2	3.2	3.3	2.05
1974	80.0	49.7	4.7	2.9	3.1	1.9

Table D.1-4. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE-POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1974 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre 1966	95.0	59.0	6.9	5.5	3.34	2.07
1966	82.0	50.9	7.1	4.4	3.61	2.24
1967	82.0	50.9	7.1	4.4	3.61	2.24
1968	70.6	43.8	7.4	4.6	4.32	2.68
1969	68.4	42.5	5.8	3.6	5.08	3.15
1970	58.5	36.3	5.0	3.6	4.35	2.70
1971	56.0	34.8	4.7	2.9	3.83	2.38
1972	51.0	31.7	4.2	2.6	3.81	2.37
1973	39.0	24.2	3.5	2.2	3.3	2.05
1974	37.0	23.0	3.2	2.0	3.0	1.9

Table D.1-5. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1975 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	86.0	53.6	9.0	5.6	3.34	2.07
1968	73.6	45.7	8.0	5.0	4.32	2.68
1969	71.4	44.3	6.3	3.9	5.08	3.15
1970	61.0	37.9	6.3	3.9	4.35	2.70
1971	58.5	36.3	5.1	3.2	4.30	2.67
1972	43.0	26.7	4.1	2.5	4.55	2.83
1973	41.0	25.5	3.8	2.4	3.5	2.2
1974	38.0	24.2	3.5	2.2	3.3	2.0
1975	9.0	5.6	1.0	0.6	3.1	1.9
High altitude						
Pre-1968	147	91.3	12.2	7.6	2.0	1.2
1968	116	72.0	9.0	5.6	2.86	1.78
1969	111	68.9	7.8	4.8	2.93	1.82
1970	99.3	61.5	7.2	4.5	3.32	2.06
1971	92.0	57.1	6.7	4.2	2.74	1.70
1972	92.0	57.1	6.2	3.9	3.08	1.91
1973	88.0	54.6	5.7	3.5	3.5	2.17
1974	84.0	52.2	5.2	3.2	3.3	2.05
1975	19.5	12.1	1.48	0.91	3.1	1.9

Table D.1-6. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1975 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	86.0	53.6	9.0	5.6	3.34	2.07
1966	83.0	51.6	7.7	4.8	3.61	2.24
1967	83.0	51.6	7.7	4.8	3.61	2.24
1968	73.6	45.7	8.0	5.0	4.32	2.68
1969	71.4	44.3	6.3	3.9	5.08	3.15
1970	61.0	37.9	6.3	3.9	4.35	2.70
1971	58.5	36.3	5.1	3.2	3.83	2.38
1972	53.0	32.9	4.5	2.8	3.81	2.37
1973	41.0	25.5	3.8	2.4	3.5	2.17
1974	38.0	24.2	3.5	2.2	2.06	1.28
1975	5.4	3.4	0.6	0.4	2.0	1.2

Table D-17. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1978 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	97.0	60.2	9.1	5.7	3.34	2.07
1968	76.6	47.6	8.6	5.3	4.32	2.68
1969	74.4	46.2	6.6	4.2	5.08	3.15
1970	63.5	39.4	6.8	4.2	4.35	2.70
1971	61.0	37.9	5.5	3.4	4.30	2.67
1972	45.0	27.9	4.4	2.7	4.56	2.83
1973	43.0	26.7	4.1	2.5	3.7	2.3
1974	41.0	25.5	3.8	2.4	3.5	2.2
1975	9.9	6.1	1.20	0.75	3.2	2.0
1976	9.0	5.6	1.0	0.6	3.1	1.9
High altitude						
Pre-1968	149	92.5	12.3	7.6	2.0	1.2
1968	121	75.1	9.7	6.0	2.86	1.78
1969	116	72.0	8.4	5.2	2.93	1.82
1970	103	64.0	7.6	4.8	3.32	2.06
1971	86.0	53.6	7.2	4.5	2.74	1.70
1972	76.0	50.6	6.7	4.2	3.08	1.91
1973	92.0	57.1	6.2	3.9	3.7	2.3
1974	88.0	54.6	5.7	3.5	3.5	2.2
1975	21.5	13.4	1.76	1.09	3.2	2.0
1976	19.5	12.1	1.45	0.91	3.1	1.9

Table D-18. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1978 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1966	97.0	60.2	9.1	5.7	3.34	2.07
1966	84.0	52.2	8.3	5.2	3.61	2.24
1967	84.0	52.2	8.3	5.2	3.61	2.24
1968	76.6	47.6	8.6	5.3	4.32	2.68
1969	74.4	46.2	6.6	4.2	5.08	3.15
1970	63.5	39.4	6.8	4.2	4.35	2.70
1971	61.0	37.9	5.5	3.4	3.83	2.37
1972	56.0	34.7	4.8	3.0	3.81	2.37
1973	43.0	26.7	4.1	2.5	3.7	2.30
1974	41.0	25.5	3.8	2.4	2.12	1.32
1975	5.9	3.7	0.7	0.4	2.06	1.28
1976	5.4	3.4	0.6	0.4	2.0	1.24

Table 0.1.9. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1977 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	98.0	60.9	9.2	5.7	3.14	2.07
1968	79.6	49.4	9.2	5.7	4.32	2.68
1969	77.4	48.1	7.3	4.5	5.08	3.15
1970	66.0	41.0	7.3	4.5	4.35	2.70
1971	63.5	39.4	6.9	3.7	4.30	2.67
1972	47.0	29.2	4.7	2.9	4.65	2.83
1973	45.0	27.9	4.4	2.7	3.9	2.4
1974	43.0	26.7	4.1	2.5	3.7	2.3
1975	10.8	6.7	1.4	0.9	3.3	2.0
1976	9.9	6.1	1.2	0.7	3.2	2.0
1977	9.0	5.6	1.0	0.6	2.0	1.2
High altitude						
Pre-1968	151	93.0	12.4	7.7	2.0	1.2
1968	126	78.2	10.4	6.5	2.80	1.78
1969	121	75.1	9.0	5.6	2.93	1.82
1970	107	66.4	8.4	5.2	3.32	2.06
1971	100	62.1	7.7	4.8	2.74	1.70
1972	100	62.1	7.2	4.5	3.08	1.91
1973	96.0	59.6	6.7	4.2	3.9	2.4
1974	92.0	57.1	6.2	3.9	3.7	2.3
1975	23.5	14.6	2.06	1.28	3.3	2.0
1976	21.5	13.4	1.76	1.09	3.2	2.0
1977	9.0	5.6	1.0	0.6	2.0	1.2

Table 0.1.10. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1977 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre-1968	98.0	60.9	9.2	5.7	3.14	2.07
1968	85.0	52.8	9.0	5.6	3.61	2.24
1969	85.0	52.8	9.0	5.6	3.61	2.24
1970	79.6	49.4	9.2	5.7	4.32	2.68
1971	77.4	48.1	7.3	4.5	5.08	3.15
1972	66.0	41.0	7.3	4.5	4.35	2.70
1973	63.5	39.4	6.9	3.7	3.83	2.38
1974	57.0	35.4	5.1	3.2	3.81	2.37
1975	45.0	27.9	4.4	2.7	3.9	2.4
1976	43.0	26.7	4.1	2.5	2.18	1.35
1977	6.5	4.0	0.8	0.5	2.12	1.32
1978	5.9	3.7	0.7	0.4	2.06	1.28
1977	5.4	3.4	0.6	0.4	1.5	0.93

Table D.1-11. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE-POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1978 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	99.0	61.5	8.3	5.8	3.34	2.07
1968	87.6	54.3	8.3	5.8	4.32	2.68
1969	80.4	49.9	7.8	4.8	5.08	3.15
1970	68.5	42.5	7.8	4.8	4.35	2.70
1971	66.0	41.0	6.3	3.9	4.30	2.67
1972	49.0	30.4	5.0	3.1	4.55	2.83
1973	47.0	29.2	4.7	2.9	4.1	2.5
1974	45.0	27.9	4.4	2.7	3.9	2.4
1975	11.7	7.3	1.6	1.0	3.4	2.1
1976	10.8	6.7	1.4	0.9	3.3	2.0
1977	9.9	6.1	1.2	0.7	2.06	1.3
1978	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
Pre 1968	153	95	12.5	7.8	2.0	1.2
1968	131	81.4	11.1	6.9	2.86	1.78
1969	126	78.2	9.6	6.0	2.93	1.82
1970	111	68.9	9.0	5.6	3.32	2.06
1971	108	64.6	8.2	5.1	2.74	1.70
1972	104	58.6	7.7	4.8	3.06	1.91
1973	100	62.1	7.2	4.5	4.1	2.5
1974	96.0	59.6	6.7	4.2	3.9	2.4
1975	25.5	15.8	2.36	1.47	3.4	2.1
1976	23.6	14.6	2.06	1.28	3.3	2.0
1977	9.9	6.1	1.2	0.6	2.06	1.3
1978	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-12. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE-POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1978 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
Pre 1968	99.0	61.5	8.3	5.8	3.34	2.07
1968	85.0	52.8	8.0	5.6	3.61	2.24
1967	85.0	52.8	8.0	5.6	3.61	2.24
1968	87.6	54.3	8.3	5.8	4.32	2.68
1969	80.4	49.9	7.8	4.8	5.08	3.15
1970	68.5	42.5	7.8	4.8	4.35	2.70
1971	66.0	41.0	6.3	3.9	4.83	2.38
1972	59.0	36.6	6.4	3.5	3.81	2.37
1973	47.0	29.2	4.7	2.9	4.1	2.55
1974	45.0	27.9	4.4	2.7	2.24	1.39
1975	7.0	4.3	1.0	0.6	2.18	1.35
1976	6.5	4.0	0.8	0.5	2.12	1.32
1977	5.9	3.7	0.7	0.4	1.56	0.97
1978	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-13. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1979 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	89.0	61.5	8.3	5.8	3.34	2.07
1968	82.6	51.3	8.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	71.0	44.1	6.3	5.2	4.35	2.70
1971	68.5	42.5	6.7	4.2	4.30	2.67
1972	61.0	37.9	5.7	3.5	4.55	2.83
1973	49.0	30.4	5.0	3.1	4.3	2.7
1974	47.0	29.2	4.7	2.9	4.1	2.5
1975	12.6	7.8	1.8	1.1	3.5	2.2
1976	11.7	7.3	1.8	1.0	3.4	2.1
1977	10.8	6.7	1.4	0.9	3.12	1.92
1978	3.1	1.9	0.32	0.20	0.29	0.18
1979	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
Pre 1968	153	95.0	12.5	7.8	2.00	1.20
1968	131	81.4	11.1	6.9	2.86	1.78
1969	131	81.4	10.2	6.3	2.93	1.82
1970	115	71.4	8.6	6.0	3.32	2.06
1971	108	67.1	8.7	5.4	2.74	1.70
1972	108	67.1	8.2	5.1	3.08	1.91
1973	103	64.0	7.7	4.8	4.3	2.7
1974	100	62.1	7.2	4.5	4.1	2.5
1975	27.5	17.1	2.66	1.65	3.5	2.2
1976	25.5	15.8	2.36	1.47	3.4	2.1
1977	10.8	6.7	1.4	0.9	3.12	1.92
1978	3.1	1.9	0.32	0.20	0.29	0.18
1979	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-14. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES—STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1979 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
1966	86.0	53.8	9.0	5.6	3.61	2.24
1967	86.0	53.8	9.0	5.6	3.61	2.24
1968	82.6	51.3	8.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	71.0	44.1	6.3	5.2	4.35	2.70
1971	68.5	42.5	6.7	4.2	3.83	2.38
1972	61.0	37.9	5.7	3.5	3.81	2.37
1973	49.0	30.4	5.0	3.1	4.30	2.70
1974	47.0	29.2	4.7	2.9	2.30	1.43
1975	7.6	4.7	1.1	0.7	2.24	1.39
1976	7.0	4.3	1.0	0.6	2.18	1.35
1977	6.5	4.0	0.8	0.5	1.62	1.01
1978	3.1	1.9	0.32	0.20	0.29	0.18
1979	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1.15. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES--EXCLUDING CALIFORNIA--FOR CALENDAR YEAR 1980 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	88.0	61.5	9.3	5.8	3.34	2.07
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	73.5	45.6	8.8	5.5	4.35	2.70
1971	71.0	44.1	7.1	4.4	4.30	2.67
1972	53.0	32.9	5.6	3.5	4.55	2.83
1973	51.0	31.7	5.3	3.3	4.5	2.8
1974	49.0	30.4	5.0	3.1	4.3	2.7
1975	13.5	8.4	2.0	1.2	3.6	2.2
1976	12.6	7.8	1.8	1.1	3.6	2.2
1977	11.7	7.3	1.6	1.0	2.18	1.35
1978	3.4	2.1	0.38	0.24	0.34	0.21
1979	3.1	1.9	0.32	0.20	0.29	0.18
1980	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
Pre 1968	153	95.0	12.5	7.8	2.9	1.8
1968	131	81.4	11.1	6.9	2.93	1.78
1969	131	81.4	10.2	6.3	2.93	1.82
1970	119	73.9	10.2	6.3	3.32	2.06
1971	112	69.6	9.2	5.7	2.74	1.70
1972	112	69.6	8.7	5.4	3.08	1.91
1973	108	67.1	8.2	5.1	4.5	2.8
1974	104	64.6	7.7	4.8	4.3	2.7
1975	29.5	18.3	2.86	1.84	3.6	2.2
1976	27.5	17.1	2.66	1.65	3.5	2.2
1977	11.7	7.3	1.6	1.0	2.18	1.35
1978	3.4	2.1	0.38	0.24	0.34	0.21
1979	3.1	1.9	0.32	0.20	0.29	0.18
1980	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1.16. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES--STATE OF CALIFORNIA ONLY--FOR CALENDAR YEAR 1980 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
1967	86.0	52.8	9.0	5.6	3.61	2.24
1968	82.6	51.3	9.3	5.8	4.32	2.68
1969	83.4	51.8	8.3	5.2	5.08	3.15
1970	73.5	45.6	8.8	5.5	4.35	2.70
1971	71.0	44.1	7.1	4.4	3.83	2.38
1972	63.0	39.1	6.0	3.7	3.81	2.37
1973	51.0	31.7	5.3	3.3	4.50	2.79
1974	49.3	30.4	5.0	3.1	2.36	1.47
1975	9.1	5.6	1.2	0.7	2.30	1.43
1976	7.6	4.7	1.1	0.7	2.24	1.39
1977	7.0	4.3	1.0	0.6	1.68	1.04
1978	3.4	2.1	0.38	0.24	0.34	0.21
1979	3.1	1.9	0.32	0.20	0.29	0.18
1980	2.8	1.7	0.27	0.17	0.24	0.15

Table 0.1-17. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1985 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbon		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1972	57.0	35.4	6.2	3.9	4.65	2.83
1973	57.0	35.4	6.2	3.9	5.0	3.1
1974	57.0	35.4	6.2	3.9	5.0	3.1
1975	18.0	11.2	3.0	1.9	4.1	2.5
1976	17.1	10.6	2.8	1.7	4.0	2.5
1977	16.2	10.1	2.6	1.6	2.48	1.54
1978	4.8	3.0	0.65	0.40	1.1	0.68
1979	4.5	2.8	0.59	0.37	0.90	0.56
1980	4.2	2.6	0.54	0.34	0.73	0.45
1981	3.9	2.4	0.49	0.30	0.56	0.35
1982	3.6	2.2	0.43	0.27	0.40	0.25
1983	3.4	2.1	0.38	0.24	0.34	0.21
1984	3.1	1.9	0.32	0.20	0.29	0.18
1985	2.8	1.7	0.27	0.17	0.24	0.15
High altitude						
1972	120	74.5	9.7	6.0	3.08	1.91
1973	120	74.5	9.7	6.0	5.0	3.1
1974	120	74.5	9.7	6.0	5.0	3.1
1975	39.5	24.5	3.46	2.15	4.1	2.5
1976	37.5	23.3	3.16	1.96	4.0	2.5
1977	16.2	10.1	2.60	1.60	2.48	1.54
1978	4.8	3.0	0.65	0.40	1.00	0.68
1979	4.5	2.8	0.59	0.37	0.90	0.56
1980	4.2	2.6	0.54	0.34	0.73	0.45
1981	3.9	2.4	0.49	0.30	0.56	0.35
1982	3.6	2.2	0.43	0.27	0.40	0.25
1983	3.4	2.1	0.38	0.24	0.34	0.21
1984	3.1	1.9	0.32	0.20	0.29	0.18
1985	2.8	1.7	0.27	0.17	0.24	0.15

Table 0.1-18. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES - STATE OF CALIFORNIA ONLY - FOR CALENDAR YEAR 1985 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbon		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1972	61.0	41.6	6.6	4.1	3.81	2.37
1973	57.0	35.4	6.2	3.9	5.0	3.1
1974	57.0	35.4	6.2	3.9	2.60	1.61
1975	16.8	6.7	1.8	1.1	2.60	1.61
1976	16.3	6.4	1.1	1.1	2.54	1.58
1977	9.1	6.0	1.6	1.0	1.98	1.23
1978	4.8	3.0	0.65	0.40	1.1	0.68
1979	4.5	2.8	0.59	0.37	0.90	0.56
1980	4.2	2.6	0.54	0.34	0.73	0.45
1981	3.9	2.4	0.49	0.30	0.56	0.35
1982	3.6	2.2	0.43	0.27	0.40	0.25
1983	3.4	2.1	0.38	0.24	0.34	0.21
1984	3.1	1.9	0.32	0.20	0.29	0.18
1985	2.8	1.7	0.27	0.17	0.24	0.15

Table D 1-19. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES— EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1990 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low and high altitude						
1977	18.0	11.2	3.0	1.9	2.6	1.6
1978	5.6	3.6	0.81	0.50	1.70	1.06
1979	5.6	3.6	0.81	0.50	1.70	1.06
1980	5.6	3.6	0.81	0.50	1.70	1.06
1981	5.3	3.3	0.76	0.47	1.50	0.93
1982	5.0	3.1	0.70	0.43	1.30	0.81
1983	4.8	3.0	0.65	0.40	1.10	0.68
1984	4.5	2.8	0.59	0.37	0.90	0.56
1985	4.2	2.6	0.54	0.34	0.73	0.45
1986	3.9	2.4	0.49	0.30	0.56	0.35
1987	3.6	2.2	0.43	0.27	0.40	0.25
1988	3.4	2.1	0.38	0.24	0.34	0.21
1989	3.1	1.9	0.32	0.20	0.29	0.18
1990	2.8	1.7	0.27	0.17	0.24	0.15

Table D 1-20. CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES— STATE OF CALIFORNIA ONLY—FOR CALENDAR YEAR 1990 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
California						
1977	10.8	6.7	1.8	1.1	2.10	1.30
1978	5.6	3.6	0.81	0.50	1.70	1.06
1979	5.6	3.6	0.81	0.50	1.70	1.06
1980	5.6	3.6	0.81	0.50	1.70	1.06
1981	5.3	3.3	0.76	0.47	1.50	0.93
1982	5.0	3.1	0.70	0.43	1.30	0.81
1983	4.8	3.0	0.65	0.40	1.10	0.68
1984	4.5	2.8	0.59	0.37	0.90	0.56
1985	4.2	2.6	0.54	0.34	0.73	0.45
1986	3.9	2.4	0.49	0.30	0.56	0.35
1987	3.6	2.2	0.43	0.27	0.40	0.25
1988	3.4	2.1	0.38	0.24	0.34	0.21
1989	3.1	1.9	0.32	0.20	0.29	0.18
1990	2.8	1.7	0.27	0.17	0.24	0.15

Table D.1-21. PARTICULATE, SULFURIC ACID, AND TOTAL SULFUR OXIDES EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES

Pollutant	Emission factors		
	Non-catalyst (Leaded fuel)	Non-catalyst (Unleaded fuel)	Catalyst (Unleaded fuel)
Particulate			
Exhaust[a]			
g/mi	0.34	0.05	0.05
g/km	0.21	0.03	0.03
Tire wear			
g/mi	0.20	0.20	0.20
g/km	0.12	0.12	0.12
Sulfuric acid			
g/mi	0.001	0.001	0.02-0.08[b]
g/km	0.001	0.001	0.01-0.04
Total sulfur oxides			
g/mi	0.13	0.13	0.13
g/km	0.08	0.08	0.08

[a]Excluding particulate sulfate or sulfuric acid aerosol.
[b]Sulfuric acid emission varies markedly with driving mode and fuel sulfur levels.

Table D.1-22. SAMPLE CALCULATION OF FRACTION OF ANNUAL LIGHT DUTY VEHICLE TRAVEL BY MODEL YEAR[a]

Age, years	Fraction of total vehicles in use nationwide (a)[b]	Average annual miles driven (b)[c]	a x b	Fraction of annual travel (m)[d]
1	0.081	15,900	1,288	0.112
2	0.110	15,080	1,658	0.143
3	0.107	14,080	1,498	0.130
4	0.106	13,100	1,389	0.121
5	0.102	12,200	1,244	0.108
6	0.096	11,300	1,085	0.094
7	0.088	10,300	906	0.079
8	0.077	9,400	724	0.063
9	0.064	8,500	544	0.047
10	0.049	7,600	372	0.032
11	0.033	6,700	221	0.019
12	0.023	6,700	154	0.013
≥13	0.064	6,700	429	0.039

[a]References 1 through 6.
[b]These data are for July 1. Data from References 2-6 were averaged to produce a value for m that is better suited for projections.
[c]Mileage values are the results of at least one later analysis of data in Reference 1.
[d]m = a/Σa.

Table 3.1.2.1. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR LIGHT-DUTY VEHICLES[a,b]

Location	Model year	$V_{SC} = e^{(A + BV + CV^2)}$						$V_{SC} = A + BV$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
		A	B	C	A	B	C	A	B
Low-H^+ air (Excluding 1966-1967 CA)[c]	1957-1967	0.953	-6.00×10^{-3}	5.01×10^{-4}	0.967	-6.07×10^{-3}	5.78×10^{-4}	0.909	-2.982×10^{-3}
California	1966-1967	0.957	-5.98×10^{-3}	5.03×10^{-4}	0.967	-6.22×10^{-3}	5.79×10^{-4}	0.944	2.798×10^{-3}
Low-altitude	1968	1.019	-6.63×10^{-3}	5.96×10^{-4}	1.047	-6.52×10^{-3}	6.01×10^{-4}	0.886	2.569×10^{-3}
	1969	1.005	-6.77×10^{-3}	5.90×10^{-4}	1.259	-7.72×10^{-3}	6.60×10^{-4}	0.915	2.422×10^{-3}
	1970	0.967	-6.70×10^{-3}	5.55×10^{-4}	1.267	-7.72×10^{-3}	6.40×10^{-4}	0.842	2.798×10^{-3}
	Post-1970	0.942	-6.62×10^{-3}	5.67×10^{-4}	1.241	-7.52×10^{-3}	6.09×10^{-4}	0.843	2.804×10^{-3}
High-altitude	1957-1967	0.953	-6.08×10^{-3}	5.52×10^{-4}	0.721	-4.57×10^{-3}	4.56×10^{-4}	0.922	2.517×10^{-3}
	1968	0.722	-4.62×10^{-3}	4.80×10^{-4}	0.642	-4.23×10^{-3}	4.33×10^{-4}	0.642	1.835×10^{-3}
	1969	0.726	-4.55×10^{-3}	4.84×10^{-4}	0.628	-4.04×10^{-3}	4.15×10^{-4}	0.726	1.453×10^{-3}
	1970	0.640	-5.23×10^{-3}	5.23×10^{-4}	0.735	-5.24×10^{-3}	4.98×10^{-4}	0.614	1.518×10^{-3}
	Post-1970	0.781	-4.95×10^{-3}	4.95×10^{-4}	0.764	-5.54×10^{-3}	4.99×10^{-4}	0.697	1.563×10^{-3}

[a] Reference 1. Equations should not be extrapolated beyond the range of the data (15 to 45 mi/hr, 24 to 72 km/hr). For speed correction factors at the speeds 15 and 10 mi/hr (5 and 16 km/hr), see Table 3.1.2.2A.

[b] The speed correction factors equations and coefficients presented in this table are expressed in terms of english units (miles per hour). In order to perform calculations using the metric system of units, it is suggested that kilometers per hour be first converted to miles per hour ($1 km/hr = 0.621 mi/hr$). Once speed correction factors are determined, all other calculations can be performed using metric units.

Table D 1-24. LOW AVERAGE SPEED CORRECTION FACTORS FOR LIGHT DUTY VEHICLES[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	2.72	1.57	2.60	1.46	1.08	1.03
California	1966-1967	1.79	1.00	1.87	1.12	1.16	1.09
Low altitude	1968	3.06	1.75	2.96	1.66	1.04	1.00
	1969	3.57	1.86	2.95	1.65	1.08	1.05
	1970	3.60	1.88	2.51	1.51	1.13	1.05
	Post 1970	4.15	2.23	2.75	1.63	1.15	1.03
High altitude	1957-1967	2.29	1.48	2.34	1.37	1.33	1.20
	1968	2.53	1.54	2.10	1.27	1.22	1.18
	1969	2.47	1.61	2.04	1.22	1.22	1.08
	1970	2.84	1.72	2.35	1.36	1.19	1.11
	Post 1970	3.00	1.83	2.17	1.35	1.06	1.02

[a]Driving patterns developed from CAPE-21 vehicle operation data (Reference 8) were input to the model emission analysis model (see section 3.1.3.3). The results predicted by the model for speeds of 5 and 10 mi/hr (8 and 16 km/hr) were divided by FTP emission factors for hot operation to obtain the above results. The above data are approximate and represent the best currently available information.

Table D 1-25. LIGHT DUTY VEHICLE TEMPERATURE CORRECTION FACTORS AND HOT/COLD VEHICLE OPERATION CORRECTION FACTORS FOR FTP EMISSION FACTORS[a]

Pollutant and controls	Temperature correction factor (z_{gp})[b]	Hot/cold vehicle operation correction factors	
		g(t)	f(t)
Carbon monoxide			
Non-catalyst	$-0.0127t + 1.95$		$0.0845t + 0.02$
Catalyst	$-0.0743t + 8.68$	$e^{(0.035t - 5.24)}$	$e^{(0.038t - 4.14)}$
Hydrocarbons			
Non-catalyst	$-0.0113t + 1.81$		$0.0870t + 0.03$
Catalyst	$-0.0304t + 3.25$	$0.0818t + 0.0886$	$0.0850t - 0.0409$
Nitrogen oxides			
Non-catalyst	$-0.0046t + 1.36$		$-0.0068t + 1.64$
Catalyst	$-0.0060t + 1.52$	$-0.0810t + 0.858$	$0.0810t + 0.835$

[a]Reference 9. Temperature (t) is expressed in °F. In order to apply the above expressions, °C must first be converted to °F ($°F = 9/5\,°C + 32$). Similarly, Kelvin (K) must be converted to °F ($°F = 9/5(K - 273.16) + 32$).

[b]The formulae for z_{gp} enable the correction of FTP emission factors for ambient temperature. The formulae for f(t) are used in conjunction with Equation D1-2 to calculate z_{gphc}. (The variable z_{gphc} is used in Equation D1-1. z_{gp} must be used also.)

where: R(i) and g(i) are given in Table D 1-35, w is the percentage of cold operation, and s is the percentage of hot start operation. For pre-1975 model year vehicles, non-catalyst factors should be used. For 1975-1977, catalyst factors should be used.

The use of catalysts after 1978 is uncertain at present. For model years 1979 and beyond, the use of those correction factors that produce the highest emission estimates is suggested in order that emissions are not underestimated. The extent of use of catalysts in 1977 and 1978 will depend on the impact of the 1979 sulfuric acid emission standard, which cannot now be predicted.

D 1.3 Crankcase and Evaporative Hydrocarbon Emission Factors

In addition to exhaust emission factors, the calculation of hydrocarbon emissions from gasoline motor vehicles involves evaporative and crankcase hydrocarbon emission factors. Composite crankcase emissions can be determined using:

$$h_0 = \sum_{i=0}^{n} h_i \, m_{i0} \qquad \text{(D1-4)}$$

where: h_0 = The composite crankcase hydrocarbon emission factor for calendar year (o)

h_i = The crankcase emission factor for the i^{th} model year

m_{i0} = The weighted annual travel of the i^{th} model year during calendar year (o)

Crankcase hydrocarbon emission factors for model year are summarized in Table D 1-36.

Table D 1-36. CRANKCASE HYDROCARBON EMISSIONS BY MODEL YEAR FOR LIGHT DUTY VEHICLES
EMISSION FACTOR RATING: B

Model year	Hydrocarbons	
	g/mi	g/km
California only		
Pre 1961	4.1	2.5
1961 through 1963	0.8	0.5
1964 through 1967	0.0	0.0
Post 1967	0.0	0.0
All areas except California		
Pre 1963	4.1	2.5
1963 through 1967	0.8	0.5
Post 1967	0.0	0.0

There are two sources of evaporative hydrocarbon emissions from light-duty vehicles: the fuel tank and the carburetor system. Diurnal changes in ambient temperature result in expansion of the air-fuel mixture in a partially filled fuel tank. As a result, gasoline vapor is expelled to the atmosphere. Running losses from the fuel tank occur as the fuel is heated by the road surface during driving, and hot soak losses from the carburetor system occur after engine shutdown at the end of a trip. Carburetor system losses occur from such locations as the carburetor vents, the float bowl, and the gaps around the throttle and choke shafts. Because evaporative emissions are a function of the diurnal variation in ambient temperature and the number of trips per day, emissions are best calculated in terms of evaporative emissions per day per vehicle. Emissions per day can be converted to emissions per mile (if necessary) by dividing the emissions per day by an average daily miles per vehicle value. This value is likely to vary from location to location, however. The composite evaporative hydrocarbon emission factor is given by:

$$e_n = \sum_{i=n-12}^{n} (g_i + k_i d)(m_{in}) \qquad (D1.5)$$

where: e_n = The composite evaporative hydrocarbon emission factor for calendar year (n) in lbs/day (g/day)

g_i = The diurnal evaporative hydrocarbon emission factor for a model year (i) in lbs/day (g/day)

k_i = The hot soak evaporative emission factor in lbs/trip (g/trip) for the i^{th} model year

d = The number of daily trips per vehicle (3.3 trips/vehicle-day is the nationwide average)

m_{in} = The weighted annual travel of the i^{th} model year during calendar year (n)

The variables g_i and k_i are presented in Table D1.27 by model year.

Table D1.27. EVAPORATIVE HYDROCARBON EMISSIONS BY MODEL YEAR FOR LIGHT DUTY VEHICLES[a] EMISSION FACTOR RATING: A

Location and model year	By source[b] Diurnal, g/day	Hot soak, g/trip	g/day[c]	Composite g/mi	g/km
Low altitude					
Pre 1970	26.0	14.7	74.5	2.53	1.57
1970 (Calif.)	16.3	10.9	62.3	1.78	1.11
1970 (non Calif.)	26.0	14.7	74.5	2.53	1.57
1971	16.3	10.9	62.3	1.78	1.11
1972-1978	12.1	12.0	51.7	1.78	1.09
Post 1979[d]	--	--	--	0.5	0.31
High altitude[e]					
Pre 1971	37.4	17.4	94.8	3.22	2.00
1971-1978	17.4	14.2	64.3	2.19	1.36
Post 1979[d]	--	--	--	0.5	0.31

[a] References 10 and 11.

[b] See text for explanation.

[c] Grams per day values are diurnal emissions plus hot soak emissions multiplied by the average number of trips per day. Nationwide data from References 1 and 2 indicate that the average vehicle is used for 3.3 trips per day. Gram/mile values were determined by dividing average g/day by the average nationwide travel per vehicle (28.8 miles/day) from Reference 2.

[d] Post-1979 evaporative emission factors are based on the assumption that existing technology can result in further control of evaporative hydrocarbons. A breakdown of post-1979 emissions by source (i.e., diurnal and hot soak) is not available.

[e] Vehicles without evaporative control were not tested at high altitude. Values presented here are the product of the ratio of pre-1971 (low altitude) evaporative emissions to 1972 evaporative emissions and 1971-1972 high altitude emissions.

D.1.4 Particulate and Sulfur Oxide Emissions

Light-duty, gasoline-powered vehicles emit relatively small quantities of particulate and sulfur oxides in comparison with emission levels of the three pollutants discussed above. For this reason, average rather than composite emission factors should be sufficiently accurate for approximating particulate and sulfur oxide emissions from light-duty, gasoline-powered vehicles. Average emission factors for these pollutants are presented in Table D.1-21. No Federal standards for these two pollutants are presently in effect, although many areas do have opacity (antismoke) regulations applicable to motor vehicles.

Sulfuric acid emission from catalysts is presently receiving considerable attention. An emission standard for that pollutant is anticipated beginning in model year 1979.

D.1.5 Basic Assumptions

Light-duty vehicle emission standards. A critical assumption necessary in the calculation of projected composite emission rates is the timetable for implementation of future emission standards for light-duty vehicles. The timetable used for light-duty vehicles in this appendix is that which reflects current legislative and administrative actions as of April 1, 1975. This schedule is:

- For hydrocarbons — 1.5 g/mi (0.93 g/km) for 1975 through 1977 model years; 0.41 g/mi (0.25 g/km) for 1978 and later model years.
- For carbon monoxide — 15 g/mi (9.3 g/km) for 1975 through 1977 model years; 3.4 g/mi (2.1 g/km) for 1978 and later model years.
- For nitrogen oxides — 3.1 g/mi (1.9 g/km) for 1975 and 1976 model years; 2.0 g/mi (1.24 g/km) for the 1977 model year; 0.4 g/mi (0.25 g/km) for 1978 and later model years.

Although the statutory standards of 0.41 g/mi for HC, 3.4 g/mi for CO, and 0.4 g/mi for NO_x are legally scheduled for implementation in 1978, consideration of increased sulfuric acid emission from catalysts, fuel economy problems and control technology availability, and reevaluation of the level of NO_x control needed to achieve the NO_2 air quality standard led the EPA Administrator to recommend to Congress that the light-duty vehicle emission control schedule be revised. The tabulated values in this appendix do not, however, reflect these recent recommendations. If Congress accepts the proposed revisions, the appropriate tables will be revised.

Deterioration and emission factors. Although deterioration factors are no longer presented by themselves in this publication, they are, nonetheless, used implicitly to calculate calendar year emission factors for motor vehicles. Based on an analysis of surveillance data,[10-11] approximate linear deterioration rates for pre-1968 model years were established as follows: carbon monoxide — 4 percent per calendar year; hydrocarbons — 4 percent per calendar year; and nitrogen oxides — 0 percent per calendar year. For 1968-1974 model years, deterioration was assumed to be 3 percent per calendar year for CO, 10 percent per calendar year for HC, and 3 percent per calendar year for NO_x. For all pre-1975 model years, linear deterioration was applied to the surveillance test results to determine tabulated values.[12] Vehicles of model year 1975 and later are assumed to have a deterioration rate of 10 percent per calendar year for CO and 30 percent per calendar year for HC. For NO_x, see the following section on credit for inspection/maintenance systems. These deterioration rates are applied to new vehicle emission factors for prototype cars.

D.1.6 Credit for Inspection/Maintenance Systems

If an Air Quality Control Region has an inspection/maintenance (I/M) program, the following credits can be applied to light-duty vehicles:

1. A 10 percent reduction in CO and HC can be applied to all model year vehicles starting the year I/M is introduced.
2. Deterioration following the initial 10 percent is assumed to follow the schedules below:

	HC	CO
Pre-1975 vehicles	2 percent per year	2 percent per year
1975 and later vehicles	12 percent per year	7 percent per year

3. This deterioration rate continues until a vehicle is 10 years old and remains stable thereafter. No catalyst replacement is assumed.

4. The NO_x emission deterioration and response to I/M is highly conjectural; the estimates below are based on the assumption of engine-out emission of 1.2 g/mi at low mileage, deterioration of engine-out emission at 4 percent per year, NO_x catalyst efficiency deterioration from 80 percent to 70 percent in the first 4 years, and a linear deterioration in average catalyst efficiency from 70 percent to zero over the next 7 years because of catalyst failures. The response to I/M without catalyst replacement is a reduction in the engine-out deterioration from 4 to 2 percent per year. One catalyst replacement is assumed for the catalyst replacement scenario. Note: There is no emission reduction due to I/M for pre-1978 vehicles.

NO_x EMISSION DETERIORATION

(Standard is 0.4 g/mi, 0.25 g/km)

Year	No I/M		I/M, no catalyst replacement		I/M, one catalyst replacement	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
1	0.24	0.15	0.24	0.15	0.24	0.15
2	0.28	0.18	0.28	0.17	0.28	0.17
3	0.34	0.21	0.33	0.20	0.33	0.20
4	0.40	0.25	0.38	0.24	0.36	0.24
5	0.50	0.35	0.52	0.32	0.39	0.24
6	0.73	0.45	0.66	0.41	0.40	0.25
7	0.90	0.56	0.81	0.50	0.47	0.29
8	1.1	0.68	0.96	0.60	0.56	0.34
9	1.3	0.81	1.12	0.70	0.63	0.39
10	1.5	0.93	1.3	0.81	0.71	0.44
10	1.7	1.1	1.5	0.93	0.80	0.50

[a] Table does not apply to pre-1978 vehicles.

0.1.7 Adjusting Emission Factor Tables for Changes in Future Light-Duty Vehicle Emission Standards

Because it is likely that Congressional action will alter the existing light-duty emission standard schedule, a methodology is presented here to enable modification of the emission factor tables (Tables 0.1.1 through 0.1.30). The emission factor tables presented in this appendix, as stated previously, reflect statutory carbon monoxide, hydrocarbon, and nitrogen oxides exhaust emission standards. If changes in the magnitude of the standards and/or the implementation dates occur, appropriate adjustments can be accomplished using Table 0.1.28. This table contains emission factors by vehicle age for a number of likely future emission standards.

In order to illustrate the proper use of Table 1.28, the following hypothetical example is given. Emission standards applicable up to and including the 1977 model year are set by law, but changes in the schedule after 1977 (beginning with 1978 models) may occur. For purposes of this example, assume that the Congress changes the existing law such that 1978-1979 model year vehicles are subject to a carbon monoxide emission standard of 9.0 g/mi, a hydrocarbon emission standard of 0.9 g/mi, and a nitrogen oxides emission standard of 2.0 g/mi. Assume also that this scenario has no effect on 1980 and later models, which remain at present statutory levels.

Table D.1-28. EXHAUST EMISSION FACTORS BY VEHICLE AGE
FOR SELECTED LIGHT-DUTY VEHICLE EMISSION STANDARDS

Vehicle age (years)[a]	Carbon monoxide								Hydrocarbons				Nitrogen oxides							
	15.0 g/mi Standard		9.0 g/mi Standard		3.4 g/mi Standard		7.0 g/mi Standard		0.9 g/mi Standard		0.41 g/mi Standard		2.0 g/mi Standard		1.5 g/mi Standard		1.0 g/mi Standard		0.4 g/mi Standard	
	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
1	9.02	5.61	5.44	3.38	2.30	1.43	1.02	0.64	0.26	0.16	0.27	0.17	2.00	1.24	1.50	0.932	1.0	0.62	0.24	0.150
2	9.09	5.65	5.58	3.47	2.37	1.47	1.22	0.76	0.31	0.19	0.32	0.20	2.06	1.28	1.56	0.97	1.04	0.65	0.25	0.155
3	10.8	6.71	6.55	4.07	2.74	1.71	1.41	0.88	0.36	0.22	0.36	0.24	2.12	1.32	1.61	1.01	1.08	0.67	0.24	0.15
4	11.7	7.23	7.10	4.41	2.95	2.22	1.49	1.02	0.39	0.24	0.42	0.27	2.18	1.35	1.66	1.04	1.12	0.70	0.40	0.2
5	12.6	7.8	7.6	4.7	2.8	2.4	1.8	1.1	1.1	0.7	0.49	0.30	2.24	1.39	1.74	1.08	1.16	0.72	0.56	0.3
6	13.5	8.4	8.1	5.0	4.2	2.6	2.0	1.2	1.2	0.7	0.54	0.34	2.30	1.43	1.80	1.12	1.20	0.75	0.72	0.45
7	14.4	8.9	8.6	5.3	4.5	2.8	2.2	1.4	1.3	0.8	0.59	0.37	2.36	1.47	1.86	1.16	1.24	0.77	0.88	0.55
8	15.3	9.5	9.2	5.7	4.8	3.0	2.4	1.5	1.4	0.9	0.65	0.40	2.42	1.50	1.91	1.19	1.28	0.79	1.1	0.6
9	16.2	10.1	9.7	6.0	5.0	3.1	2.6	1.6	1.6	1.0	0.70	0.43	2.48	1.54	1.95	1.23	1.32	0.82	1.2	0.8
10	17.1	10.6	10.2	6.4	5.3	3.3	2.8	1.7	1.7	1.1	0.76	0.47	2.54	1.58	2.04	1.27	1.36	0.84	1.5	0.9
11+	18.0	11.2	10.8	6.7	5.6	3.5	3.0	1.9	1.8	1.1	0.81	0.50	2.60	1.61	2.10	1.30	1.40	0.87	1.7	1.05

[a] Vehicle age refers to the number of full calendar years. For example, age zero means vehicle less than 12 months old.

This change in the standard schedule affects the tabulated values for the 1978 and 1979 model years presented in Tables D.1-11 through D.1-20. In other words, every number in every column in these tables headed with "1978 or 1979" model year must be completely changed. The appropriate replacement values are summarized in Table D.1-28. The age of the vehicle refers to a year in a vehicle's life. For example, the 1978 *model* year vehicles are assumed to be age one in *calendar* year 1978, age two in *calendar* year 1979 and so on.

To change the 1978 model year column in Table D.1-11 to reflect our hypothetical Congressional action, the appropriate values are extracted from the first row (age one) of Table D.1-28. For a 9.0 g/mi CO standard, the age one emission factor for both low and high altitude locations is 5.4 g/mi (3.4 g/km). This value is used to replace the existing value [2.8 g/mi (1.7 g/km)] in the 1978 column of Table D.1-11. A similar procedure is used for hydrocarbons and nitrogen oxides.

To illustrate a slightly more complicated situation, consider the revision of Table D.1-16 to reflect our hypothetical situation. All the values in the 1978 and 1979 columns must be changed. In 1980, the 1978 model year vehicles are age three; thus from Table D.1-28, the appropriate carbon monoxide emission factor is 6.5 g/mi (4.0 g/km). This value replaces the existing value of 3.4 g/mi (2.1 g/km). The 1979 model year carbon monoxide emission factor is 5.9 g/mi (3.7 g/km), replacing the existing Table D.1-16 value of 3.1 g/mi (1.9 g/km). This procedure is followed, using Table D.1-28, for all three pollutants. The procedure is similar for other standard schedules and other calendar year tables.

The above methodology was designed to enable the user of this document to quickly revise the tables. Any Congressional action will result in revision of the appropriate tables by EPA. Publication of these revised tables takes time, however, and although every effort is made by EPA to make these changes quickly, the required lead time is such that certain users may want to perform the modifications to the tables in advance. The standards covered in Table D.1-28 represent the most likely values Congress will adopt, but by no means represent all possible standards.

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D.2 LIGHT-DUTY, GASOLINE-POWERED TRUCKS

D.2.1 General

This class of vehicles includes all trucks with a gross vehicle weight (GVW) of 8500 lb (3856 kg) or less. It is comprised of vehicles that formerly were included in the light-duty truck (6000 lb - 8500 lb GVW) and under) and the heavy-duty vehicle (<8001 lb - 8500 lb GVW and over) classes. Generally, these trucks are used for personal transportation as opposed to commercial use.

D.2.2 FTP Exhaust Emissions

Projected emission factors for light trucks are summarized in Tables D.2-1 through D.2-12. For information on projected emission factors for vehicles operated in California and at high altitude, see sections D.2.5 and D.2.6. The basic methodology used for projecting light-duty vehicle emission factors (section D.1 of this appendix) also applies to this class. As in section D.1, the composite emission factor for light-duty trucks is given by:

$$e_{ystsw} = \sum_{i=0}^{n} e_{ipst} \, m_{iy} \, s_{ips} \, z_{ipt} \, b_{ipsw} \qquad \text{(D.2-1)}$$

where e_{ystsw} = Composite emission factor in g/mi (g/km) for calendar year (y), pollutant (p), average speed (s), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (s)

e_{ipst} = The 1975 Federal Test Procedure mean emission factor for the i^{th} model year light-duty trucks during calendar year (y) and for pollutant (p)

m_{iy} = The fraction of annual travel by the i^{th} model year light-duty trucks during calendar year (y)

s_{ips} = The speed correction factor for the i^{th} model year light-duty trucks for pollutant (p) and average speed (s)

z_{ipt} = The temperature correction for the i^{th} model year light-duty trucks for pollutant (p) and ambient temperature (t)

b_{ipsw} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty trucks for pollutant (p), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (s)

Values for m_{iy} are given in Table D.2-11. Unless other data are available, s_{ips} (Tables D.2-13 and D.2-13), z_{ipt} and b_{ipsw} (Table D.2-14) are the same for this class as for light-duty vehicles.

Table D.2.1. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE-POWERED TRUCKS – EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1973 (BASED ON 1975 FEDERAL TEST PROCEDURE)

...ication and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	125.0	77.6	17.0	10.6	4.2	2.6
1968	70.0	43.5	7.9	4.9	4.9	3.0
1969	67.8	42.1	5.9	3.7	5.3	3.3
1970	56.0	34.8	5.4	3.4	5.2	3.2
1971	56.0	34.8	4.7	2.9	5.2	3.2
1972	45.9	27.9	3.8	2.4	5.3	3.3
1973	42.8	26.6	3.6	2.2	4.4	2.7

Table D.2.2. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE-POWERED TRUCKS EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1974 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	125.0	77.6	17.0	10.6	4.2	2.6
1968	73.5	45.6	8.7	5.4	4.9	3.0
1969	71.3	44.3	6.5	4.0	5.3	3.3
1970	58.5	36.3	6.0	3.7	5.2	3.2
1971	58.5	36.3	5.2	3.2	5.2	3.2
1972	47.2	29.3	4.2	2.6	5.3	3.3
1973	46.0	27.9	4.0	2.5	4.6	2.9
1974	42.8	26.6	3.6	2.2	4.4	2.7

Table D 2.3. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1975 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.6	17.0	10.6	4.2	2.6
1968	77.0	47.8	9.5	5.9	4.9	3.0
1969	74.8	46.5	7.1	4.4	5.3	3.3
1970	61.0	37.9	6.6	4.1	5.2	3.2
1971	61.0	37.9	5.7	3.5	5.2	3.2
1972	49.4	30.7	4.6	2.9	5.3	3.3
1973	47.2	29.3	4.4	2.7	4.8	3.0
1974	45.0	27.6	4.0	2.5	4.6	2.9
1975	27.0	16.8	2.7	1.7	4.4	2.7

Table D 2.4. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1976 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1968	125	77.6	17.0	10.6	4.2	2.6
1968	80.6	50.0	10.1	6.3	4.9	3.0
1969	78.3	48.6	7.7	4.8	5.3	3.3
1970	63.5	39.4	7.2	4.5	5.2	3.2
1971	63.5	39.4	6.2	3.9	5.2	3.2
1972	51.6	32.0	5.0	3.1	5.3	3.3
1973	49.4	30.7	4.8	3.0	5.0	3.1
1974	47.2	29.3	4.4	2.7	4.8	3.0
1975	28.5	17.7	3.0	1.9	4.6	2.9
1976	27.0	16.8	2.7	1.7	4.4	2.7

Table D.2-5. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1977 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	125	77.5	17.0	10.6	4.2	2.6
1968	84.0	52.2	11.1	6.9	4.9	3.0
1969	81.8	50.8	8.3	5.2	5.3	3.3
1970	66.0	41.0	7.8	4.8	5.2	3.2
1971	66.0	41.0	6.7	4.2	5.2	3.2
1972	53.8	33.4	5.4	3.4	5.3	3.3
1973	51.6	32.0	5.2	3.2	5.2	3.2
1974	49.4	30.7	4.8	3.0	5.0	3.1
1975	30.0	18.6	3.3	2.0	4.8	3.0
1976	28.5	17.7	3.0	1.9	4.6	2.9
1977	27.0	16.8	2.7	1.7	4.4	2.7

Table D.2-6. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1978

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	125	77.6	17.0	10.6	4.2	2.6
1968	87.5	54.3	11.9	7.4	4.9	3.0
1969	85.3	53.0	8.9	5.5	5.3	3.3
1970	68.5	42.5	8.4	5.2	5.2	3.2
1971	68.5	42.5	7.2	4.5	5.2	3.2
1972	56.0	34.8	5.8	3.6	5.3	3.3
1973	53.8	33.4	5.6	3.5	5.4	3.4
1974	51.6	32.0	5.2	3.2	5.2	3.2
1975	31.5	19.6	3.6	2.2	5.0	3.1
1976	30.0	18.6	3.3	2.0	4.8	3.0
1977	28.5	17.7	3.0	1.9	4.6	2.9
1978	9.8	6.1	1.0	0.6	2.3	1.4

Table D.2.7. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1979
(BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	125	77.6	17.0	10.6	4.2	2.6
1968	87.5	54.3	11.9	7.4	4.9	3.0
1969	88.8	55.1	9.5	5.9	5.3	3.3
1970	71.0	44.1	9.0	5.6	5.2	3.2
1971	71.0	44.1	7.7	4.8	5.2	3.2
1972	68.2	36.1	6.2	3.9	5.3	3.3
1973	56.0	34.8	6.0	3.7	5.6	3.5
1974	53.8	33.4	5.6	3.5	5.4	3.4
1975	33.0	20.5	3.9	2.4	5.2	3.2
1976	31.5	19.6	3.6	2.2	5.0	3.1
1977	30.0	18.6	3.3	1.4	4.8	3.0
1978	10.8	6.7	1.2	0.7	2.35	1.46
1979	9.8	6.1	1.0	0.6	2.3	1.4

Table D.2.8. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS—EXCLUDING CALIFORNIA—FOR CALENDAR YEAR 1980
(BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1968	125	77.6	17.0	10.6	4.2	2.6
1968	87.5	54.3	11.9	7.4	4.9	3.0
1969	88.8	55.1	9.5	5.9	5.3	3.3
1970	73.5	45.6	9.0	5.6	5.2	3.2
1971	73.5	45.6	8.2	5.1	5.2	3.2
1972	60.4	37.5	6.6	4.1	5.3	3.3
1973	56.2	36.1	6.4	4.0	5.6	3.6
1974	56.0	34.8	6.0	3.7	5.6	3.5
1975	34.5	21.4	4.2	2.6	5.4	3.4
1976	33.0	20.5	3.9	2.4	5.2	3.2
1977	31.5	19.6	3.6	2.2	5.0	3.1
1978	11.8	7.3	1.4	0.9	2.4	1.5
1979	10.8	6.7	1.2	0.7	2.35	1.46
1980	9.8	6.1	1.0	0.6	2.3	1.4

Table 0.2-9. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1985 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1972	64.8	40.2	7.4	4.6	5.3	3.3
1973	64.8	40.2	7.0	4.7	6.4	4.0
1974	64.8	40.2	7.6	4.7	6.4	4.0
1975	42.0	26.1	5.7	3.5	6.4	4.0
1976	40.5	25.1	5.4	3.4	6.2	3.9
1977	39.0	24.2	5.1	3.2	6.0	3.7
1978	16.8	10.4	2.4	1.5	2.65	1.65
1979	15.8	9.8	2.2	1.4	2.6	1.6
1980	14.8	9.2	2.0	1.2	2.55	1.58
1981	13.8	8.6	1.8	1.1	2.5	1.6
1982	12.8	7.9	1.6	1.0	2.45	1.52
1983	11.8	7.3	1.4	0.9	2.4	1.5
1984	10.8	6.7	1.2	0.7	2.35	1.46
1985	9.8	6.1	1.0	0.6	2.3	1.4

Table D.2-10. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED TRUCKS - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1980 (BASED ON 1975 FEDERAL TEST PROCEDURE)

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1977	42.0	26.1	3.7	3.5	6.4	4.0
1978	19.8	11.3	3.0	1.9	2.8	1.74
1979	19.8	12.3	3.0	1.9	2.8	1.74
1980	19.8	12.3	3.0	1.9	2.8	1.74
1981	18.8	11.7	2.8	1.7	2.75	1.71
1982	17.8	11.1	2.6	1.6	2.7	1.68
1983	16.8	10.4	2.4	1.5	2.65	1.65
1984	15.8	9.8	2.2	1.4	2.6	1.61
1985	14.8	9.2	2.0	1.2	2.55	1.58
1986	13.8	8.7	1.8	1.1	2.5	1.55
1987	12.8	7.9	1.6	1.0	2.45	1.52
1988	11.8	7.3	1.4	0.9	2.4	1.49
1989	10.8	6.7	1.2	0.7	2.35	1.46
1990	9.8	6.1	1.0	0.6	2.3	1.43

Table D.2-11. SAMPLE CALCULATION OF FRACTION OF ANNUAL LIGHT DUTY, GASOLINE POWERED TRUCK TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (m)[c]
1	0.061	15,900	970	0.094
2	0.097	15,000	1,455	0.141
3	0.097	14,000	1,358	0.132
4	0.097	13,100	1,270	0.123
5	0.083	12,200	1,013	0.098
6	0.076	11,300	859	0.083
7	0.076	10,300	783	0.076
8	0.063	9,400	592	0.057
9	0.054	8,500	459	0.044
10	0.043	7,600	327	0.032
11	0.036	6,700	241	0.023
12	0.024	6,700	161	0.016
≥13	0.185	4,500	832	0.081

[a] Vehicles in use by model year - of 1972 (Reference 1 and 2).
[b] Reference 2.
[c] m = ab/Σab

TABLE 2.2-12. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR LIGHT-DUTY TRUCKS[a]

Location	Model year	$V_{SC} = e^{(A + BS + CS^2)}$						$V_{SC} = A + BS$	
		Hydrocarbons			Carbon monoxide			Nitrogen oxides	
		A	B	C	A	B	C	A	B
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}	0.936	0.486×10^{-2}
California	1966-1967	0.957	-5.98×10^{-2}	5.63×10^{-4}	0.981	-6.22×10^{-2}	6.19×10^{-4}	0.944	0.786×10^{-2}
Low altitude	1968	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}	0.888	0.0934×10^{-2}
	1969	1.005	-6.27×10^{-2}	5.80×10^{-4}	1.009	-7.72×10^{-2}	8.66×10^{-4}	0.915	0.422×10^{-2}
	1970	0.901	-5.70×10^{-2}	5.59×10^{-4}	1.007	-7.72×10^{-2}	8.40×10^{-4}	0.943	0.749×10^{-2}
	Post-1970	0.943	-5.92×10^{-2}	5.67×10^{-4}	1.041	-7.52×10^{-2}	8.09×10^{-4}	0.942	0.804×10^{-2}
High altitude	1957-1967	0.883	-5.58×10^{-2}	5.52×10^{-4}	0.727	-4.57×10^{-2}	4.56×10^{-4}	0.602	2.027×10^{-2}
	1968	0.722	-4.63×10^{-2}	4.80×10^{-4}	0.662	-4.23×10^{-2}	4.23×10^{-4}	0.642	1.835×10^{-2}
	1969	0.706	-4.55×10^{-2}	4.64×10^{-4}	0.628	-4.04×10^{-2}	4.25×10^{-4}	0.726	1.462×10^{-2}
	1970	0.840	-5.33×10^{-2}	5.33×10^{-4}	0.835	-5.24×10^{-2}	4.99×10^{-4}	0.674	1.978×10^{-2}
	Post-1970	0.787	-4.95×10^{-2}	4.99×10^{-4}	0.894	-5.54×10^{-2}	4.99×10^{-4}	0.657	1.553×10^{-2}

[a] Reference 2. Equations should not be extended beyond the range of data (15 to 45 mi/hr). These data are for light-duty vehicles and are assumed applicable to light-duty trucks.

Table D.2-13. LOW AVERAGE SPEED CORRECTION FACTORS FOR LIGHT DUTY TRUCKS[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low altitude (Excluding 1966-1967 Calif.)	1957-1967	2.72	1.57	2.50	1.45	1.08	1.04
California	1966-1967	1.79	1.00	1.87	1.12	1.16	1.09
Low altitude	1968	3.06	1.75	2.96	1.66	1.04	1.00
	1969	3.57	1.86	2.95	1.65	1.08	1.05
	1970	3.60	1.88	2.51	1.51	1.13	1.06
	Post-1970	4.15	2.23	2.75	1.63	1.15	1.03
High altitude	1957-1967	2.20	1.48	2.34	1.37	1.33	1.20
	1968	2.43	1.54	2.10	1.27	1.22	1.18
	1969	2.47	1.61	2.04	1.22	1.22	1.08
	1970	2.84	1.72	2.35	1.36	1.19	1.11
	Post-1970	3.00	1.83	2.17	1.35	1.06	1.02

[a] Driving patterns developed from CAPE-21 vehicle operation data (Reference 4) were input to the model emission analysis model (see section 3.1.2.3). The results predicted by the model for emissions at 5 and 10 mi/hr (8 and 16 km/hr) were divided by 2 FTP emission factors for operation to obtain the above results. The above data are approximate and represent the best currently available information.

Table D.2-14. LIGHT DUTY TRUCK TEMPERATURE CORRECTION FACTORS AND HOT/COLD VEHICLE OPERATION CORRECTION FACTORS FOR FTP EMISSION FACTORS[a]

Pollutant and controls	Temperature correction factor (r_{tpt})[b]	Hot/cold vehicle operation correction factors	
		q(t)	T(t)
Carbon monoxide			
Non catalyst	$-0.0127t + 1.95$		$0.0345t + 0.02$
Catalyst	$-0.0743t + 6.68$	$e^{0.0351t - 5.24}$	$e^{0.0361t - 4.14}$
Hydrocarbons			
Non catalyst	$-0.0113t + 1.81$		$0.0079t + 0.03$
Catalyst	$-0.0304t + 3.25$	$0.0018t + 0.0095$	$0.0060t - 0.0409$
Nitrogen oxides			
Non catalyst	$-0.0046t + 1.36$		$-0.0068t + 1.64$
Catalyst	$-0.0060t + 1.52$	$-0.0010t + 0.858$	$0.0010t + 0.835$

[a] Reference 5. Temperature (t) is expressed in °F. In order to apply the above equations, °C must first be converted to °F. (°F = 9/5(°C + 32). Similarly, Kelvin (K) must be converted to °F. (°F = 9/5(K − 273.16) + 32).

[b] The formulae for r_{tpt} enable the correction of FTP emission factors for ambient temperature. The formulae for f(t) are used in conjunction with equation D.1-2 to calculate r_{tpwv}. If the variable r_{otwv} is used in equation D.1-1, r_{tpt} must be used also. See section D1 for appropriate formulae for calculating r_{otwv}.

For pre-1975 model year vehicles, noncatalyst temperature correction factors should be used. For 1975-1977 model year vehicles, temperature-dependent correction factors should be calculated for the catalyst and noncatalyst class, and the results weighted into an overall factor that is two-thirds catalyst, one-third noncatalyst. For 1978 and later model year vehicles, noncatalyst temperature correction factors should be applied.

D.2.3 Evaporative and Crankcase Emissions

In addition to exhaust emission factors, evaporative crankcase hydrocarbon emissions are determined using:

$$f_n = \sum_{i=n-13}^{n} h_i m_{in} \qquad (D2.3)$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^{th} model year. Emission factors for this source are reported in Table D.2.15. The crankcase and evaporative emissions reported in the table are added together to arrive at this variable.

m_{in} = The weighted annual travel of the i^{th} model year vehicle during calendar year (n)

Table D.2.15. CRANKCASE AND EVAPORATIVE HYDROCARBONS EMISSION FACTORS FOR LIGHT DUTY, GASOLINE-POWERED TRUCKS
EMISSION FACTOR RATING: B

Location	Model years	Crankcase emissions[a]		Evaporative emissions[b]	
		g/km	g/mi	g/km	g/mi
All areas except high altitude and California[c]	Pre-1963	2.9	4.6	2.2	3.6
	1963-1967	1.5	2.4	2.2	3.6
	1968-1970	0.0	0.0	2.2	3.6
	1971	0.0	0.0	1.9	3.1
	1972-1979	0.0	0.0	1.9	3.1
	Post-1979[d]	0.0	0.0	0.3	0.5
High altitude	Pre-1963	2.9	4.6	2.9	4.6
	1963-1967	1.5	2.4	2.9	4.6
	1968-1970	0.0	0.0	2.9	4.6
	1971-1979	0.0	0.0	2.4	3.9
	Post-1979[d]	0.0	0.0	0.3	0.5

[a] Reference 6. Tabulated values were determined by assuming that two-thirds of the light-duty trucks are 6000 lbs GVW (2700 kg) and under, and that one-third are 6001-8500 lbs GVW (2700-3860 kg).

[b] Light-duty vehicle evaporative data (section 3.1.2) and heavy-duty vehicle evaporative data (section 3.1.4) were used to estimate the listed values.

[c] For California: Evaporative emissions for the 1970 model year are 1.9 g/km (3.1 g/mi) all other model years are the same as those reported as "All area except high altitude and California". Crankcase emissions for the pre-1981 California light-duty trucks are 4.6 g/mi (2.9 g/km), 1981-1983 model years are 2.4 g/mi (1.5 g/km), all post-1983 model year vehicles are 0.0 g/mi (0.0 g/km).

[d] Post-1979 evaporative emission factors are based on the assumption that existing technology, when applied to the entire light truck class, can result in further control of evaporative hydrocarbons.

D.2.4 Particulate and Sulfur Oxides Emissions

Particulate and sulfur oxides emission factors are presented in Table D.2-10.

Table D.2-10. PARTICULATE, SULFURIC ACID, AND TOTAL SULFUR OXIDES EMISSION FACTORS FOR LIGHT DUTY, GASOLINE POWERED VEHICLES

Pollutant	Emission factors		
	Non catalyst (Leaded fuel)	Non catalyst (Unleaded fuel)	Catalyst (Unleaded fuel)
Particulate			
Exhaust[a]			
g/mi	0.34	0.05	0.06
g/km	0.21	0.03	0.03
Tire wear			
g/mi	0.20	0.20	0.20
g/km	0.12	0.12	0.12
Sulfuric acid			
g/mi	0.001	0.001	0.02-0.06[b]
g/km	0.001	0.001	0.01-0.04
Total sulfur oxides			
g/mi	0.18	0.18	0.18
g/km	0.11	0.11	0.11

[a]Excluding particulate sulfate or sulfuric acid aerosol.
[b]Sulfuric acid emission varies markedly with driving mode and fuel sulfur levels.

D.2.5 Basic Assumptions

Composition of class. For emission estimation purposes, this class is composed of trucks having a GVW of 8500 lb (3856 kg) or less. Thus, this class includes the group of trucks previously defined in AP-42 as light-duty vehicles (LDV) plus a group of vehicles previously defined as heavy-duty vehicles (HDV). On the basis of numbers of vehicles nationwide, the split is two-thirds LDVs, one-third HDVs.

Standards. The pollutant standards assumed for this category are weighted averages of the standards applicable to the various vehicle classes that were combined to create the light-duty truck class. Until 1975, those light-duty trucks that weighed 6000 lb (2722 kg) and under were required to meet light-duty vehicle emission standards. Beginning in 1975, in accordance with a court order, a separate light truck class was created. This class, which comprises two-thirds of the light-duty truck class (as defined here), is required to meet standards of 39 g/mi (12.4 g/km) of carbon monoxide, 3 g/mi (1.2 g/km) of hydrocarbons, and 3.1 g/mi (1.9 g/km) of nitrogen oxides from 1975 through 1977. The remaining one-third of the light-duty trucks are currently subject to heavy-duty vehicle standards. Data presented in section D.2 are based on the assumption that, beginning in 1978, the light-duty truck class of 0-8500 lb (3856 kg) GVW will be subject to the following standards: carbon monoxide 17.9 g/mi (11.1 g/km), hydrocarbon 1.65 g/mi (1.0 g/km), and nitrogen oxides 2.3 g/mi (1.4 g/km).

Deterioration. The same deterioration assumptions discussed in section D.1 for light-duty vehicles apply except that 1975-1977 model year vehicles weighing between 6001 and 8500 lb (2722-3856 kg) are assumed not to be equipped with catalytic converters. Therefore, the deterioration factors for light-duty trucks are weighted values as opposed to 6000 lb (2722 kg) GVW truck deterioration values and 6001 to 8500 lb (2722-3856 kg) GVW truck deterioration values. The weighting factors are two-thirds and one-third, respectively.

Actual emission values. For 1972 and earlier model year vehicles, emission values are those measured in the EPA Emission Surveillance Program[7,8] and the baseline study of 6,000- to 10,000-lb (2,722-4,536 kg) trucks.[9,10]

The tabulated values are weighted two-thirds for 0-6000 lb (0-2722 kg) trucks and one-third for 6000- to 8500-lb (2722-3856 kg) trucks. For 1975-1976 model year emission values, this same weighting factor is applied to projected 1973-1974 light-duty vehicle emissions and 1972 model year 6,000- to 10,000-lb (2,722-4,536 kg) emission values. 1975-1977 model year emission values for 0- to 6000-lb (0 to 2722 kg) GVW trucks are based on unpublished certification test data along with estimates of prototype-to-production differences. Post-1977 model year emission values are based on previous relationships of low mileage in-use emission values to the standards.

California values. Projected emission factors for vehicles operated in California were not computed because of a lack of information. The Pre-1975 California light-duty vehicle ratios can be applied to the light-duty trucks as a best estimate (see section D.1). For 1975 and later, no difference is expected except in the value for nitrogen oxides in 1975-1976; the California standards can be weighted two-thirds, and the truck baseline value of 7.1 g/mi (4.4 gm/km) one-third to get an estimated value for nitrogen oxides in 1975-1976.

D.2.6 High Altitude and Inspection/Maintenance Corrections

To correct for high altitude for all pollutants for light-duty trucks, the light-duty vehicle ratio of high altitude to low altitude emission factors for the model year vehicle is applied to the calendar year in question (see section D.1). Credit for inspection/maintenance for light-duty trucks is the same as that given for autos in section D.1. of this appendix.

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D.3 LIGHT-DUTY, DIESEL-POWERED VEHICLES

D.3.1 General

Although light-duty diesels represent only a small fraction of automobiles in use, their numbers can be expected to increase in the future. Currently, only two manufacturers produce diesel-powered automobiles for sale in the United States, but this may change as the demand for a low polluting, economical engines grows.

D.3.2 Emissions

Because of the limited data base for these vehicles, no attempt has been made to predict deterioration factors. The composite emission factor calculation procedure involves only the Federal Test Procedure (FTP) emission factor and the fraction of travel by model year (see main text, section 3.1.3). The values presented in Table 3.1.3-1 apply to all model years and pollutants.

D.3.3 Basic Assumptions

Standards. See section D.1, Light Duty, Gasoline-Powered Vehicles.

Deterioration. Because of the lack of data, no deterioration factors are assumed. Diesels are expected to continue to emit carbon monoxide and hydrocarbons at their present rates but to meet future NO_x standards exactly.

D.4 HEAVY-DUTY, GASOLINE-POWERED VEHICLES

D.4.1 General

This class includes vehicles with a gross vehicle weight of more than 8500 lb (3856 kg). Most of the vehicles are trucks; however, buses and special purpose vehicles such as motor homes are also included. As in other sections of this appendix the reader is encouraged to refer to the main text (see section 3.1.4) for a much more detailed presentation. The discussion presented here is brief, consisting primarily of data summaries.

D.4.2 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emissions

The composite exhaust emission factor is calculated using:

$$e_{nps} = \sum_{i=0}^{n} e_{ipn}\, m_{in}\, v_{ips} \qquad \text{(D.4-1)}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n) pollutant (p), and average speed (s)

e_{ipn} = The test procedure emission factor for pollutant (p) in g/mi (g/km) for the i^{th} model year in calendar year (n)

m_{in} = The weighted annual travel of the i^{th} model year vehicles during calendar year (n). The determination of this variable involves the use of the vehicle year distribution.

v_{ips} = The speed correction factor for the i^{th} model year vehicles for pollutant (p) and average speed (s)

The projected test procedure emission factors (e_{ipn}) are summarized in Tables D.4-1 through D.4-10. These projected factors are based on the San Antonio Road Route test (see section 3.1.4) and assume 100 percent warmed-up vehicle operation at an average speed of approximately 18 mi/hr (29 km/hr). Table D.4-11 contains a sample calculation of the variable m_{in}, using nationwide statistics. Speed correction factor data are contained in Table D.4-12 and Table D.4-13.

Table D.4-1. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES – EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1975

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.9	4.2
1970	189	117	14.9	9.6	12.1	7.5
1971	188	117	14.3	8.8	12.6	7.8
1972	189	117	13.7	8.5	12.6	7.8
1973	188	117	13.6	8.4	12.5	7.8

Table D.4-2. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES – EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1974

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.0	8.7	12.7	7.9
1971	188	117	13.9	8.6	12.7	7.9
1972	188	117	13.9	8.6	12.6	7.8
1973	188	117	13.7	8.5	12.6	7.8
1974	167	104	13.1	8.1	12.5	7.8

Table D.4-3. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES – EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1975

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.1	8.8	12.8	7.9
1971	188	117	14.0	8.7	12.7	7.9
1972	188	117	13.9	8.6	12.7	7.9
1973	188	117	13.8	8.6	12.6	7.8
1974	168	104	13.2	8.2	12.6	7.8
1975	167	104	13.1	8.1	12.5	7.8

Table D.4-4. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES – EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1976

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.2	8.8	12.8	7.9
1971	188	117	14.1	8.8	12.8	7.9
1972	188	117	14.0	8.7	12.7	7.9
1973	188	117	13.9	8.6	12.7	7.9
1974	169	105	13.3	8.3	12.6	7.8
1975	168	104	13.2	8.2	12.6	7.8
1976	167	104	13.1	8.1	12.5	7.8

Table D.4-5. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1977

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.3	8.9	12.9	8.0
1971	188	117	14.2	8.8	12.8	7.9
1972	188	117	14.1	8.8	12.8	7.9
1973	188	117	14.0	8.7	12.7	7.9
1974	170	106	13.4	8.3	12.7	7.9
1975	169	105	13.3	8.3	12.6	7.8
1976	168	104	13.2	8.2	12.6	7.8
1977	167	104	13.1	8.1	12.5	7.8

Table D.4-6. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1978

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.4	8.9	12.9	8.0
1971	188	117	14.3	8.9	12.9	8.0
1972	188	117	14.2	8.8	12.8	7.9
1973	188	117	14.1	8.8	12.8	7.9
1974	171	106	13.5	8.4	12.7	7.9
1975	170	106	13.4	8.3	12.7	7.9
1976	169	105	13.3	8.3	12.6	7.8
1977	168	104	13.2	8.2	12.6	7.8
1978	117	73	9.0	5.7	11.4	7.1

Table D.4-7. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE-POWERED VEHICLES - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1979

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.4	8.9	13.0	8.1
1971	188	117	14.4	8.9	12.8	8.0
1972	188	117	14.3	8.9	12.9	8.0
1973	188	117	14.2	8.8	12.8	7.9
1974	172	107	13.6	8.4	12.8	7.9
1975	171	106	13.5	8.4	12.7	7.9
1976	170	106	13.4	8.3	12.7	7.9
1977	169	105	13.3	8.3	12.6	7.8
1978	118	73	6.0	3.7	11.6	7.2
1979	117	73	6.0	3.7	11.4	7.1

Table D.4-8. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE-POWERED VEHICLES - EXCLUDING CALIFORNIA - FOR CALENDAR YEAR 1980

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre-1970	238	148	35.4	22.0	6.8	4.2
1970	188	117	14.4	8.9	13.0	8.1
1971	188	117	14.4	8.9	13.0	8.1
1972	188	117	14.4	8.9	12.9	8.0
1973	188	117	14.3	8.9	12.9	8.0
1974	173	107	13.7	8.5	12.8	7.9
1975	172	107	13.6	8.4	12.8	7.9
1976	171	106	13.5	8.4	12.7	7.9
1977	170	106	13.4	8.3	12.7	7.9
1978	119	74	6.1	3.8	11.8	7.3
1979	118	73	6.0	3.7	11.6	7.2
1980	117	73	6.0	3.7	11.4	7.1

Table D.4-9. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES – EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1985

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1972	188	117	14.4	8.9	13.0	8.1
1973	188	117	14.4	8.9	13.0	8.1
1974	176	109	14.0	8.7	13.0	8.1
1975	176	109	14.0	8.7	13.0	8.1
1976	175	109	14.0	8.7	12.9	8.0
1977	174	108	13.9	8.6	12.9	8.0
1978	124	77	8.3	5.0	12.8	7.9
1979	123	76	8.2	5.0	12.6	7.8
1980	122	76	8.2	5.0	12.4	7.7
1981	121	75	8.2	5.0	12.2	7.6
1982	120	75	8.1	5.0	12.0	7.5
1983	119	74	8.1	5.0	11.8	7.3
1984	118	73	8.1	5.0	11.6	7.2
1985	117	73	8.0	5.0	11.4	7.1

Table D.4-10. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES – EXCLUDING CALIFORNIA – FOR CALENDAR YEAR 1990

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1977	176	109	14.0	8.7	13.0	8.1
1978	126	78	8.3	5.0	13.0	8.1
1979	126	78	8.3	5.0	13.0	8.1
1980	126	78	8.2	5.0	13.0	8.1
1981	126	78	8.2	5.0	13.0	8.1
1982	125	78	8.2	5.0	13.0	8.1
1983	124	77	8.2	5.0	12.8	7.9
1984	123	76	8.2	5.0	12.6	7.8
1985	122	76	8.2	5.0	12.4	7.7
1986	121	75	8.1	5.0	12.2	7.6
1987	120	75	8.1	5.0	12.0	7.5
1988	119	74	8.1	5.0	11.8	7.3
1989	118	73	8.0	5.0	11.6	7.3
1990	117	73	8.0	5.0	11.4	7.1

Table 8.4.11. SAMPLE CALCULATION OF FRACTION OF ANNUAL HEAVY DUTY, GASOLINE POWERED VEHICLE TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (m)[c]
1	0.037	19,000	703	0.062
2	0.078	18,000	1,404	0.124
3	0.078	17,000	1,326	0.117
4	0.078	16,000	1,248	0.110
5	0.075	14,000	1,050	0.093
6	0.075	12,000	900	0.080
7	0.075	10,000	750	0.066
8	0.068	9,500	646	0.057
9	0.059	9,000	531	0.047
10	0.053	8,500	451	0.040
11	0.044	8,000	352	0.031
12	0.032	7,500	240	0.021
13	0.247	7,000	1,729	0.153

[a] Vehicles in use by model year as of 1972 (Reference 1).
[b] Reference 1.
[c] m = ab/Σab.

Table D.4.13. LOW AVERAGE SPEED CORRECTION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES[a]

Location	Model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low altitude	Pre-1970	2.72	1.57	2.50	1.45	1.08	1.03
	Post-1969	3.06	1.75	2.86	1.66	1.04	1.00
High altitude	Pre-1970	2.29	1.48	2.34	1.37	1.33	1.20
	Post-1969	2.43	1.54	2.10	1.27	1.22	1.15

[a]Driving patterns developed from CAPE-21 vehicle operation data (Reference 3) were input to the model emission analysis model (see section 3.1.2.3). The results predicted by the model (emissions at 8 and 16 km/hr; 5 and 10 mi/hr) were divided by FTP emission factors for hot operation to obtain the above results. The above data represent the best currently available information for light duty vehicles. These data are assumed applicable to heavy duty vehicles given the lack of better information.

D.4.3 Crankcase and Evaporative Hydrocarbons

In addition to exhaust emission factors, the calculation of evaporative and crankcase hydrocarbon emissions are determined using:

$$f_n = \sum_{i=1}^{n-1} h_i m_{in} \qquad (D.4.3)$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n).

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^{th} model year. Emission factors for this source are reported in Table D.4.14. Crankcase and evaporative emissions must be combined before applying equation D.4.3.

m_{in} = The weighted annual travel of the i^{th} model year vehicle during calendar year (n).

Table D.4.14. CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR HEAVY DUTY, GASOLINE POWERED VEHICLES
EMISSION FACTOR RATING: B

Location	Model years	Crankcase emissions[b]		Evaporative emissions[c]	
		g/mi	g/km	g/mi	g/km
All areas except high altitude & California	Pre-1968	5.7	3.5	5.8	3.6
	Post-1967[d]	0.0	0.0	5.8	3.6
California only	Pre-1964	5.7	3.5	5.8	3.6
	Post-1963[d]	0.0	0.0	5.8	3.6
High altitude	Pre-1968	5.7	3.5	7.4	4.6
	Post-1967[d]	0.0	0.0	7.4	4.6

[a]References 4 through 6 were used to estimate evaporative emission factors for heavy duty vehicles (HDV). The formula from section 3.1.2.5 was used to calculate g/mi (g/km) values. (evaporative emission factor = g + kd). The HDV diurnal evaporative emissions (g) were assumed to be three times the LDV value to account for the larger size fuel tanks used on HDV. Nine trips per day (d = number of trips per day) from Reference 3 were used in conjunction with the LDV hot soak emissions (i) to yield a total evaporative emission rate in grams per day. This value was divided by 36.2 miles per day (58.3 km/day) from Reference 1 to obtain the per mile (per kilometer) rate.

[b]Crankcase factors are from Reference 7.

[c]HDV evaporative emissions are expected to be controlled in 1978. Assume 50 percent reduction over the above (post-1967 values (post-1963 California).

D.4.4 Sulfur Oxide and Particulate Emissions

Projected sulfur oxide and particulate emission factors for all model year heavy-duty, gasoline-powered vehicles are presented in Table D.4-15. Sulfur oxides factors are based on fuel sulfur content and fuel consumption. (Sulfuric acid emissions are between 1 and 3 percent of sulfur oxides emissions.) Tire-wear particulate factors are based on automobile test results, a premise necessary because of the lack of data for heavy-duty vehicles. Truck tire wear is likely to result in greater particulate emission than that for automobiles because of larger tires, heavier loads on tires, and more tires per vehicle. Although the factors presented in Table D.4-15 can be adjusted for the number of tires per vehicle, adjustments cannot be made to account for the other differences.

Table D.4-15. SULFUR OXIDES AND PARTICULATE EMISSION FACTORS FOR HEAVY DUTY, GASOLINE-POWERED VEHICLES
EMISSION FACTOR RATING: B

Pollutant	Emissions	
	g/mi	g/km
Particulate		
Exhaust[a]	0.91	0.56
Tire wear[b]	0.201	0.121
Sulfur oxides[c] (SO_x as SO_2)	0.36	0.22

[a] Calculated from the Reference 8 value of 13 lb/10^3 gal (1.46 g/liter) gasoline. A 6.0 mi/gal (2.6 km/liter) value from Reference 9 was used to convert to a per kilometer (per mile) emission factor.

[b] Reference 10. The data from this reference are for passenger cars. In the absence of specific data for heavy duty vehicles, they are assumed to be representative of truck tire-wear particulate. An adjustment is made for trucks with more than four tires. T equals the number of tires divided by four.

[c] Based on an average fuel consumption of 6.0 mi/gal (2.6 km/liter) from Reference 9, on a 0.04 percent sulfur content from References 11 and 12, and on a density of 6.1 lb/gal (0.73 kg/liter) from References 11 and 12.

D.4.5 Basic Assumptions

Emission factors for heavy-duty vehicles (HDV) are based on San Antonio Road Route data for controlled (1970-1973 model years) trucks[13] and for uncontrolled (pre-1970 model years) trucks.[14] Unpublished data on 1974 trucks and technical judgment were used to estimate emission factors for post-1973 HDV. In doing so, it was assumed that diesel trucks will take over most of the "heavy" HDV market (trucks weighing more than 13,000 kg) and that the average weight of a gasoline-powered HDV will be approximately 26,000 lbs (11,790 kg). It is expected that interim standards for HDV, which will result in significant HC reduction, will be implemented in 1978.

Projected emission factors at high altitude and for the State of California are not reported in these tables; however, they can be derived using the following methodologies. Although all pre-1975 model year HDV emission factors for California vehicles are the same as those reported in these tables, the hydrocarbon and nitrogen oxides values for 1975-1977 model years in California can be assumed equal to the national (tabulated) values for the 1978 model year. Carbon monoxide levels for 1975-1977 HDV in California can be assumed to be 9 percent lower than the 1975-1977 national levels. To convert the national HDV levels for high altitude for all pollutants in a given calendar year, the light-duty vehicle (LDV) ratio of high altitude to low altitude emission factors (by pollutant) can be used. For pre-1970 model year trucks, the pre-1968 model year LDV ratio can be applied. For 1970-1973 model year trucks, the 1968 model year LDV ratio can be applied. For 1974-1977 trucks, the 1970 LDV ratio can be applied. For post-1977 trucks, the 1975 model year LDV ratio can be applied. See section D.1 of this appendix to obtain the data necessary to calculate these ratios.

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D.5 HEAVY-DUTY, DIESEL-POWERED VEHICLES

D.5.1 General

This class of vehicles includes all diesel vehicles with a gross vehicle weight (GVW) of more than 6000 lb (2722 kg). On the highway, heavy-duty diesel engines are primarily used in trucks and buses. Diesel engines in any application demonstrate operating principles that are significantly different from those of the gasoline engine.

D.5.2 Emissions of Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides

Emissions from heavy-duty, diesel-powered vehicles during a calendar year (n) and for a pollutant (p) can be approximately calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} e_{ipn}\, m_{in}\, v_{ips} \qquad \text{(D.5-1)}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), and average speed (s)

e_{ipn} = The emission rate in g/mi (g/km) for the i^{th} model year vehicles in calendar year (n) over a transient urban driving schedule with average speed of approximately 18 mi/hr

m_{in} = The fraction of total heavy-duty diesel miles (km) driven by the i^{th} model year vehicles during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year heavy-duty diesel vehicles for pollutant (p) and average speed (s)

Values for e_{ipn} are given in Table D.5-1; values for m_{in} are in Table D.5-2. The speed correction factor (v_{ips}) can be computed using data in Table D.5-3. Table D.5-3 gives heavy-duty diesel HC, CO, and NO_x emission factors in grams per minute for idle operation, for an urban route with average speed of 18 mi/hr (29 km/hr), and for operation at an over-the-road speed of 681 mi/hr (97 km/hr).

Table D.5.2. SAMPLE CALCULATION OF FRACTION OF ANNUAL HEAVY DUTY, DIESEL POWERED VEHICLE TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (mi)[c]
1	0.077	70,000	5,390	0.096
2	0.135	70,000	9,450	0.169
3	0.134	70,000	9,380	0.168
4	0.131	70,000	9,170	0.164
5	0.099	62,000	6,138	0.110
6	0.080	60,000	4,800	0.086
7	0.082	46,000	3,772	0.067
8	0.062	43,000	2,666	0.048
9	0.045	42,000	1,890	0.034
10	0.033	30,000	990	0.018
11	0.025	25,000	625	0.011
12	0.015	25,000	375	0.007
≥13	0.064	25,000	1,600	0.029

[a]Vehicles in use by model year as of 1972 (Reference 2).
[b]Reference 2.
[c]mi = mi/total mi

Table D.5.3. EMISSION FACTORS FOR HEAVY DUTY, DIESEL POWERED VEHICLES UNDER DIFFERENT OPERATING CONDITIONS[a]
(g/min)
EMISSION FACTOR RATING: B

Pollutant	Operating mode		
	Idle	Urban (18 mi/hr; 29 km/hr)	Over the road (60 mi/hr; 97 km/hr)
Carbon monoxide	0.64	8.61	5.40
Hydrocarbons	0.32	1.38	2.25
Nitrogen oxides (NO_x as NO_2)	1.03	6.27	29.3

[a]Data are obtained by analysis of results in Reference 1.

For average speeds less than 18 mi/hr (29 km/hr), the correction factor is:

$$F_{ips} = \frac{\text{Urban} + \left(\frac{18}{S} - 1\right)\text{Idle}}{\text{Urban}} \qquad \text{(D.5-2)}$$

Where: s is the average speed of interest (in mi/hr), and the urban and idle values (in g/min) are obtained from Table D.5-3. For average speeds above 18 mi/hr (29 km/hr), the correction factor is:

$$F_{ips} = \frac{\frac{18}{S}\left[(60\,S)\,\text{Urban} + (5.18)\,\text{Over the Road}\right]}{\text{Urban}} \qquad \text{(D.5-3)}$$

Where: S is the average speed (in mi/hr) of interest. Urban and over-the-road values (in g/min) are obtained from Table D.5-3. Emission factors for heavy-duty diesel vehicles assume all operation to be under warmed-up vehicle conditions. Temperature correction factors, therefore, are not included because ambient temperature has minimal effects on warmed-up operation.

8.5.3 Emissions of Other Pollutants

Emissions of sulfur oxides, sulfuric acid, particulate, aldehydes, and organic acids are summarized in Table 8.5-4.

Table 8.5-4. SULFUR OXIDES, PARTICULATE, ALDEHYDES, AND ORGANIC ACIDS EMISSION FACTORS FOR HEAVY DUTY, DIESEL POWERED VEHICLES
EMISSION FACTOR RATING: B

Pollutant	Emissions[a]	
	g/mi	g/km
Particulate	1.3	0.81
Sulfur oxides[b] (SO_x as SO_2)	2.8	1.7
Aldehydes (as HCHO)	0.3	0.2
Organic acids	0.3	0.2

[a]Reference 3. Particulate does not include tire wear; see heavy duty gasoline vehicle section for tire wear emission factors.
[b]Data based on assumed fuel sulfur content of 0.20 percent. A fuel economy of 4.6 mi/gal (2.0 km/liter) was used from Reference 4. Sulfuric acid emissions range from 0.5 - 3.0 percent of the sulfur oxides emissions, with the best estimate being 1 percent. These estimates are based on engineering judgment rather than measurement data.

8.5.4 Basic Assumptions

Hydrocarbon and carbon monoxide levels for heavy-duty diesel vehicles until model year 1978 are given by Reference 1. An interim standard for diesel HDV that will restrict nitrogen oxides levels, but not hydrocarbon or carbon monoxide levels, is expected to be implemented in 1978. For purposes of the projections, the nitrogen oxides standard was assumed to be 9 gm/hp-hr per brake horsepower per hour. Nitrogen oxide emission standards in California for 1975-1977 model year HDV are assumed to be equivalent to the national levels in 1978; hydrocarbon and carbon monoxide levels in California will be the same as national levels. A separate table is not given for California, but emissions are the same as those reported in Table 8.5-1, with the exception of the 1975-1977 model years. It is assumed that the effect of altitude on diesel emissions is minimal and can be considered negligible.[3]

References for Section 8.5

1. Ingalls, M. N. and K. J. Springer. Mass Emissions from Diesel Trucks Operated Over a Road Course. Southwest Research Institute, San Antonio, Texas. Prepared for Environmental Protection Agency, Ann Arbor, Mich. Under Contract No. 68-01-2113. Publication No. EPA-460/3-74-017. August 1974.

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3. Young, L. C. Unpublished emission factor data on diesel engines. Engine Manufacturers Association Emission Standards Committee, Chicago, Ill. October 16, 1974.

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D.6 MOTORCYCLES

D.6.1 General

Motorcycles are becoming an increasingly popular mode of transportation as reflected by steady increases in sales over the past few years. A detailed discussion of motorcycles may be found in section 3.1.7.

D.6.2 Carbon Monoxide, Hydrocarbon, and Nitrogen Oxides Exhaust Emissions

The composite exhaust emission factor is calculated using:

$$e_{aps} = \sum_{i=0-12}^{i_o} e_{ipa}\, m_{ia}\, v_{ips} \qquad \text{(D.6-1)}$$

where: e_{aps} = Composite emission factor in g/mi (g/km) for calendar year (a), pollutant (p), and average speed (s)

e_{ipa} = The test procedure emission factor for pollutant (p) in g/mi (g/km) for the i^{th} model year in calendar year (a)

m_{ia} = The weighted annual travel of the i^{th} model year vehicles during calendar year (a). The determination of this variable involves the use of the vehicle year distribution.

v_{ips} = The speed correction factor for the i^{th} model year vehicles for pollutant (p) and average speed (s)

The emission factor results of the Federal Test Procedure (e_{ipa}) as modified for motorcycles are summarized in Tables D.6-1 through D.6-6. Table D.6-7 contains a sample calculation of the variable m_{ia} using nationwide statistics.[3] Because there are no speed correction factor data for motorcycles, the variable v_{ips} will be assumed to equal one. The emission factor for particulate, sulfur oxide, and aldehyde and for crankcase and evaporative hydrocarbons are presented in Table D.6-8.

Table D.6-1. PROJECTED CARBON MONOXIDE, HYDROCARBON AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR PRE-1977 AND 1977 CALENDAR YEARS

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1977[a, b]	30.6	19.0	8.1	5.0	0.2	0.1
1977[b]	28.0	17.4	6.0	3.1	0.25	0.16

[a] Factors for pre 1977 calendar years.
[b] Factors for calendar year 1977.

Table D.6.2. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1978

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	29.4	18.3	5.5	3.4	0.25	0.16
1978	28.0	17.4	5.0	3.1	0.25	0.16

Table D.6.3. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1979

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	30.6	19.0	6.0	3.7	0.25	0.16
1978	29.4	18.3	5.5	3.4	0.25	0.16
1979	28.0	17.4	5.0	3.1	0.25	0.16

Table D.6.4. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1980

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	30.6	19.0	6.5	4.0	0.25	0.16
1978	30.6	19.0	6.0	3.7	0.25	0.16
1979	29.4	18.3	5.5	3.4	0.25	0.16
1980	28.0	17.4	5.0	3.1	0.25	0.16

Table D.6.5. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1986

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
Pre 1977	30.6	19.0	8.1	5.0	0.2	0.1
1977	30.6	19.0	8.1	5.0	0.25	0.16
1978	30.6	19.0	8.1	5.0	0.25	0.16
1979	30.6	19.0	8.0	5.0	0.25	0.16
1980	30.6	19.0	7.5	4.7	0.25	0.16
1981	30.6	19.0	7.0	4.3	0.25	0.16
1982	30.6	19.0	6.5	4.0	0.25	0.16
1983	30.6	19.0	6.0	3.7	0.25	0.16
1984	29.4	18.3	5.5	3.4	0.25	0.16
1985	2.1	1.3	0.41	0.25	0.4	0.2

Table D.6.6. PROJECTED CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDES EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1990

Location and model year	Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	g/mi	g/km	g/mi	g/km	g/mi	g/km
Low altitude						
1977	30.6	19.0	8.1	5.0	0.25	0.16
1978	30.6	19.0	8.1	5.0	0.25	0.16
1979	30.6	19.0	8.1	5.0	0.25	0.16
1980	30.6	19.0	8.1	5.0	0.25	0.16
1981	30.6	19.0	8.1	5.0	0.25	0.16
1982	30.6	19.0	8.1	5.0	0.25	0.16
1983	30.6	19.0	8.1	5.0	0.25	0.16
1984	30.6	19.0	8.0	5.0	0.25	0.16
1985	3.1	1.9	0.81	0.50	0.4	0.25
1986	2.9	1.8	0.73	0.45	0.4	0.25
1987	2.7	1.7	0.65	0.40	0.4	0.25
1988	2.5	1.6	0.57	0.35	0.4	0.25
1989	2.3	1.4	0.49	0.30	0.4	0.25
1990	2.1	1.3	0.41	0.25	0.4	0.25

Table D.6.7. SAMPLE CALCULATION OF FRACTION OF ANNUAL MOTORCYCLE TRAVEL BY MODEL YEAR

Age, years	Fraction of total vehicles in use nationwide (a)[a]	Average annual miles driven (b)[b]	a x b	Fraction of annual travel (m)[c]
1	0.04	2,500	100	0.064
2	0.20	2,100	420	0.268
3	0.19	1,800	342	0.218
4	0.16	1,600	256	0.163
5	0.10	1,400	140	0.089
6	0.09	1,200	108	0.069
7	0.05	1,100	55	0.035
8	0.03	1,000	30	0.019
9	0.03	950	29	0.019
10	0.02	900	18	0.011
11	0.0005	850	4	0.003
>12	0.085	800	68	0.043

[a]Vehicles in use by model year as of 1974 (Reference 2)
[b]Reference 3
[c]m = ab/Σab

Table D.6.6. SULFUR OXIDE, ALDEHYDE, AND CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR MOTORCYCLES[a]

Pollutant	Emissions			
	2 stroke engine		4 stroke engine	
	g/mi	g/km	g/mi	g/km
Hydrocarbons				
Crankcase[b]			0.60	0.37
Evaporative[c]	0.36	0.22	0.36	0.22
Particulates	0.33	0.21	0.046	0.029
Sulfur oxides[d] (SO_x as SO_2)	0.038	0.024	0.022	0.014
Aldehydes (RCHO as HCHO)	0.11	0.068	0.047	0.029

[a]Reference 1.
[b]Most 2 stroke engines use crankcase induction and produce no crankcase losses.
[c]Evaporative emissions were calculated assuming that carburetor losses were negligible. Diurnal breathing of the fuel tank is function of fuel vapor pressure, vapor space in the tank, and diurnal temperature variation; was assumed to account for all the evaporative losses associated with motorcycles. The value presented is based on average vapor pressure, vapor space, and temperature variation.
[d]Calculated using a 0.043 percent sulfur content (by weight) for regular fuel used in 2 stroke engines and 0.022 percent sulfur content (by weight) for premium fuel used in 4 stroke engines.

D.6.3 Basic Assumptions

Baseline emission data are from Reference 1. The motorcycle population was assumed to be 60 percent 4 stroke and 40 percent 2 stroke.

For the interim standards, deterioration factors for 1977 through 1984 were assumed to be: 10 percent per calendar year for hydrocarbons, 5 percent per calendar year for carbon monoxide, and 0 percent per calendar year for nitrogen oxides. For 1985 and beyond, deterioration factors are: 20 percent per calendar year for hydrocarbon, 10 percent per calendar year for carbon monoxide, and 0 percent per calendar year for nitrogen oxides. Motorcycles are assumed to deteriorate until they reach uncontrolled emission values. The deterioration rate is a fixed percentage of base year emissions.

References for Section D.6

1. Hare, C. T. and K. J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part III, Motorcycles. Final Report. Southwest Research Institute, San Antonio, Texas. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. EHS 70-108. Publication No. APTD-1492. March 1973.

2. Motorcycle Usage and Owner Profile Study. Hendrix, Tucker and Walder, Inc., Los Angeles, Calif. March 1974.

D.7 ALL HIGHWAY VEHICLES

D.7.1 General

Emission factors for 1972 for all major classes of highway vehicle are summarized in section 3.1.1. A number of scenarios that embody a range of local conditions, such as different ambient temperatures and average route speeds, are considered. Although similar data for calendar years 1973 through 1990 are presented here, only one scenario is presented. This single scenario is presented because it is general in nature and, therefore, most appropriate for a range of applications. The authors, however, believe that projections of any significance should be based on the data and methodologies presented in sections D.1 through D.6 of this appendix. The data presented in this section are, clearly, only approximations and are useful only for rough estimates.

The scenario considers the four major highway vehicle classes: light-duty, gasoline-powered vehicles (LDV); light-duty, gasoline-powered trucks (LDT); heavy-duty, gasoline-powered vehicles (HDV); and heavy-duty, diesel-powered vehicles (HDD). An average route speed of approximately 19.6 mi/hr (31.6 km/hr) is assumed. The ambient temperature is assumed to be 24°C (75°F). Twenty percent of LDV and LDT operation is considered to be in a cold operation; all HDV and HDD operation is taken to be in warmed-up condition. The percentage of total vehicular travel by each of the vehicle classes is based on nationwide data.[1-3] The percentage of travel by class is assumed to be 80.4 percent by LDV, 11.8 percent by LDT, 4.6 by HDV, and 3.2 percent by HDD.

D.7.2 Emissions

Emissions for the five pollutants for all highway vehicles are presented in Table D.7.1. The results are only an approximate indication of how future emission-controlled vehicles will influence the overall emissions from the fleet of vehicles on the road. These values do not apply to high altitude areas, nor do they apply to vehicles in the State of California.

Table D.7.1. AVERAGE EMISSION FACTORS FOR HIGHWAY VEHICLES FOR SELECTED CALENDAR YEARS

Calendar year	Carbon monoxide		Hydrocarbons		Nitrogen oxides		Sulfur oxides[a]		Particulate	
	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
1973	71.6	44.4	10.1	6.3	4.9	3.0	0.23	0.14	0.61	0.38
1974	67.5	41.9	9.4	5.8	4.8	3.0	0.23	0.14	0.61	0.38
1975	61.1	37.9	8.8	5.5	4.8	3.0	0.23	0.14	0.59	0.37
1976	54.6	33.9	8.0	5.0	4.8	3.0	0.22	0.14	0.57	0.35
1977	48.3	30.0	7.2	4.5	4.6	2.9	0.22	0.14	0.54	0.34
1978	42.7	26.5	6.6	4.1	4.3	2.7	0.21	0.13	0.51	0.32
1979	36.8	22.9	6.1	3.8	4.0	2.4	0.21	0.13	0.49	0.30
1980	31.0	19.3	5.4	3.4	3.6	2.2	0.20	0.12	0.47	0.29
1985	16.7	9.8	2.7	1.7	2.4	1.5	0.19	0.12	0.41	0.25
1990	11.3	7.0	1.9	1.2	2.0	1.3	0.19	0.12	0.40	0.25

[a] Fuel sulfur levels may be reduced in the future. If so, sulfur oxides emissions will be reduced proportionately.

References for Section D.7

1. Highway Statistics 1971. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. 1973. p. 81

3. 1972 Census of Transportation. Truck Inventory and Use Survey. U.S. Department of Commerce, Bureau of the Census, Washington, D.C. 1974.